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Secondary mathematics education in the age of STEM: Tensions and possibilities for policy and practice in NSW.

by Jane Leigh Martin

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(Principal Supervisor) and Associate Professor Mary
Coupland (Co-Supervisor)

University of Technology Sydney
Faculty of Arts and Social Science

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, J*ane Leigh Martin,* declare that this thesis, is submitted in fulfilment of the requirements for the award of *DOCTOR OF PHILOSOPHY*, in the *SCHOOL OF EDUCATION, FACULTY OF ARTS AND SOCIAL SCIENCES* at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

Models of integrated learning are commonly promoted in STEM education policies worldwide. The role of mathematics appears to sit uneasily in these models, with mathematical learning generally limited to process-driven applications offering little scope for conceptual development. With improvement in the mathematics achievement and ambition of secondary students fundamental to STEM education policies, an emerging research literature has questioned this ambiguous role of mathematics in integrated STEM. Focusing explicitly on mathematics, this study explores this tension by investigating the landscape of STEM education in NSW secondary schools that developed pursuant to the introduction of strategies promoting integrated STEM.

Using a mixed methods approach, insights into the perspectives, understandings and experiences of major stakeholders involved in secondary mathematics education – teachers, regulators, tertiary educators and external STEM providers and advisors - were gained by interviews, a web survey and document analysis. Analysis confirmed findings from previous research, including a confused understanding of integrated STEM education in the secondary school environment and a focus on technology or science in implemented programs. Mathematics content in integrated STEM was limited in quantity and scope and curriculum documents difficult to align and reconcile. Rejecting a 'teacher deficit' explanation of implementation challenges, this study questions the implementation assumptions of integrated STEM models, exposing vulnerabilities suggesting that they are ill-suited to discipline-specific education structures and do not represent sustainable models of change for secondary mathematics education. Further, the widespread finding that mathematics is trivialised in integrated STEM indicates that, on cost-benefit and epistemological bases, popular conceptions of integrated STEM may be inadequate to support a robust learning of mathematics. Nevertheless, although disillusioned with the role assigned to mathematics in integrated STEM, mathematics teachers recognised the benefits of the connected learning approach of STEM and sought to develop these approaches for mathematics within the mathematics classroom.

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Chapter 1. Introduction

The promise of STEM (Science, Technology, Engineering and Mathematics) in school education lies in it bringing together learning in the essential knowledge economy subjects using interdisciplinary or integrated curriculum approaches. Inherent in these approaches are student-centred pedagogies fostering critical thinking and problem-solving skills. This merging of key disciplinary learning with 21st century behaviours appear, in theory, to resolve the contradiction faced by education systems world-wide in the knowledge economy – how to improve student *academic achievement* in these key disciplines whilst at the same time developing the critical *behavioural skills* needed to compete in the global marketplace. STEM school education policies have been introduced worldwide since the early 21st century and share these common aims. However, as STEM education evolves, there has been growing unease in the education community about whether the school STEM education models and frameworks commonly adopted by policy makers and advocated by the education research community can ‘work’ within the education systems into which they have been inserted, and thus deliver the changes anticipated by the policy vision. This unease has been expressed by way of widespread lack of understanding and confusion on the part of educators about what STEM education actually means and looks like in the classroom, together with implementation challenges within existing school and curriculum structures. Mathematics learning in implemented STEM programs in schools has come under particular scrutiny, with concerns that the integrated curriculum model diminishes the rigour of mathematics learning to superficial processes. The promotion of approaches to STEM education that appear to neglect or be indifferent to mathematics learning present an impasse at the centre of the stated aims of any STEM education policy.

The aim of this research was to explore these concerns by investigating the overall landscape of STEM education for mathematics that emerged in NSW secondary schools pursuant to the *National STEM School Education Strategy* [NSSES] (Education Council, 2015) and NSW school STEM strategies. The NSW government did not produce a ‘stand-alone’ publication detailing an overall STEM strategy. As it relates to schools, it was published on websites hosted by the NSW Department of Education [DoE] and its regulatory authority NSW Education Standards Authority [NESA]. The dimensions of the landscape captured in this research encompass the *overall perceptions and experiences of stakeholders* in implementing the STEM education agenda for mathematics in NSW, together with *an analysis of the mathematics learning taking place in implemented STEM programs* as detailed in exemplar documents in the regulatory environment. Together, these dimensions form a spectrum of equal probity offering insights into the overall nature of STEM education for mathematics in NSW secondary schools. In describing these dimensions, this study departs from previous research by its focus on the *overall* implementation response from various important vantage points, rather than on the implementation of specific, research-driven programs or models in secondary schools. In doing so, it acknowledges the dissonance between the use and understanding of STEM education in the public arena and in education research. Additionally, by analysing the mathematics learning in secondary STEM programs in the NSW context and curriculum documents, this study is uniquely positioned *to respond to research concerns* about the ambivalent role of mathematics in STEM education programs and inconsistencies in stage learning, language and conventions in the STEM curriculum documents in NSW.

As a head teacher of mathematics in a NSW secondary school at the time the NSSES and NSW school STEM strategies were announced, I found the concept of *integrated* STEM education introduced by these strategies compelling. This conception of STEM education, distinct from simply education in the component disciplines, appeared to hold the promise of reversing the seemingly intractable decline in Australian student achievement and interest in the STEM subjects, particularly senior science and mathematics (Education Council, 2015; Productivity Commission, 2017). Having previously collaborated to develop an optional course taking *extra-curricular* concepts of mathematics into design, I approached STEM education with considerable enthusiasm, intrigued by how *curriculum learning* across the three STEM disciplines mandated in the NSW curriculums[1] could be connected and combined within the school environment.

However, beyond the sweeping vision of the policy and strategy statements, I found that the rhetoric surrounding school STEM education lacked clarity and coherence within the lived reality of the school environment. Definitions of STEM education in the strategies were inconsistent and confusing. Terms such as “interdisciplinary”, ”cross-disciplinary” and “integrated” (Education Council, 2015, pp. 5, 10; NSW Department of Education, 2016d, para. 1), were used interchangeably and without explanation, and relevant literature offered a labyrinthine range of definitions, models, conceptual arguments and frameworks. The magnitude of the implementation endeavour for an integrated STEM program appeared accessible only on a large-scale basis involving a whole-school focus (see, for example, advice on the Stem Support pages from the NSW Education Standards Authority, 2017c), precluding more limited individual attempts to introduce connected curriculum STEM learning in the classroom. Successful implementation of an integrated STEM program also appeared consequent upon prolonged partnership with, or patronage from, external organisations (see for example Capraro et al., 2016; Han et al., 2016; Tytler et al., 2019; Williams et al., 2016), support that is not accessible by or available to all schools, nor envisaged by the policy and strategy documents. It was difficult to comprehend where this integrated approach to STEM education belonged within the existing single-discipline education structure in NSW and how the vision of the strategies could be realised for all students.

1.1. Background to this research

The STEM education tsunami arrived on Australian shores with the introduction of the *National STEM School Education Strategy 2016-2026* [NSSES] in 2015 (Education Council, 2015). The acronym STEM had become familiar, used routinely by the media and politicians to describe the range of knowledges and skills

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[1] In NSW, Science and Mathematics are compulsory to year 10 and Technology (Mandatory) until year 8.

considered essential to prospering in the global knowledge economy. A number of influential government reports in various OECD countries had created a sense of urgency around STEM knowledges by predicting economic instability due to forecast shortfalls in the STEM-skilled workforces of nations (for example, the 2002 UK *SET for Success* (Roberts, 2002) report and the 2007 US *Rising above the Gathering Storm* (National Research Council [NRC], 2007) report), and Australia was no exception (see the *Health of Australian Science* (OCS, 2012a) and *Mathematics, Engineering and Science in the National Interest* (Office of the Chief Scientist [OCS], 2012b)). Focus had turned to the role of K-12 school education in boosting the STEM knowledges of school students, and as a result, in the early years of the 21st century STEM education policies and strategies had been introduced worldwide, in developed and developing countries alike (for example, European Schoolnet, 2018; Gonzalez & Kuenzi, 2012; HM Treasury, 2004; Ismail, 2018; Marginson et al., 2013; The Parliamentary Office of Science and Technology [POST], 2013). Although each STEM education policy varied with the local context, common was a focus on improving school education outcomes in the STEM disciplines, particularly in senior level science and mathematics. The NSSES and state and territory counterpart strategies implemented pursuant to Australia's federalist system of government[2] shared these goals (Timms et al., 2018).

When talking about STEM education, it is necessary to be mindful of the context in which the term is used. In popular and political usage, STEM education refers simply to education in the disciplines of science, technology, engineering and mathematics. However, among the academic education research community, it has been interpreted as delivering education in the component disciplines using innovative pedagogies (Timms et al., 2018), and in particular some form of integrated or interdisciplinary curriculum model (Blackley & Howell, 2015; Cavalcanti & Mohr-Schroder, 2019; Honey et al., 2014; Larson, 2017). The STEM education of the political and public arena is tied firmly to economic goals, whereas the STEM education of the education arena is concerned with transforming learning using student-centred

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[2] Australia has a federalist system, with state and territory governments responsible for the delivery and regulation of school education.

pedagogies. As is common in the grey literature of policy and strategy statements, STEM education policies and strategies tend to draw meaning and justification from both contexts, moving between and combining the public and academic understandings without notice or explanation (Baptista et al., 2020). As a result, the term is poorly understood by teachers (Breiner et al., 2012; English, 2016b; Holmlund et al., 2018; Martín-Páez et al., 2019; Nadelson et al., 2012; Weinberg & Sample McMeeking, 2017) and there is little shared language or understanding of STEM between teachers, researchers and policy makers (LaForce et al., 2016; Meyer et al., 2010; Wang et al., 2011; Weinberg & Sample McMeeking, 2017). It is not uncommon for schools to advertise a focus on STEM (Baker, 2019; McNally, 2017), referring simply to the provision of specialist resources[3] to support achievement in the school STEM subjects or extra-curricular programs[4], without any mention of pedagogical innovation. A further source of confusion is the term 'integrated' itself. Apart from not being understood by educators, it does not describe the single-discipline structure of the Australian education system, nor that of any other system into which STEM education has been inserted (Creese et al., 2016; Way et al., 2016).

Although STEM education might still considered as in its initial stages of development (Martín-Páez et al., 2019), many concerns have persistently been raised that are common to education jurisdictions worldwide. Integrated STEM education has not proven easy to implement in schools, requiring substantive *a priori* whole-school reforms in timetabling and resource allocation, as well as presenting significant challenges to teachers themselves. Considerable time is required to collaborate to develop an integrated STEM program, exacerbated by a lack of quality curriculum-based resources (Guzey et al., 2016; Peterman et al., 2017; Sahin & Top, 2015; Stohlmann et al., 2011), and secondary teachers in particular feel ill-equipped, both in

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[3] See for example https://www.sydneysciencecollege.nsw.edu.au, https://www.westbournecollege.com.au,https://www.ravenswood.nsw.edu.au/discover/secondary/stem, https://www.stcatherines.nsw.edu.au/Our_Approach/Pages/STEM.aspx and https://www.schoolsplus.org.au/news-details/google-schools-plus-support-stem-education-western-sydney/

[4] https://www.queenwood.nsw.edu.au/About/FAQs

terms of content and pedagogy, to teach in an integrated STEM environment (Becker & Park, 2011; Kanadli, 2019; Kelley & Knowles, 2016; Stinson et al., 2009; Weinberg & Sample McMeeking, 2017). Additionally, the integrated curriculum approach of STEM education remains a "persistently problematic curriculum practice at the school and classroom level" (Munro, 2017, p. 36), as subject-specialist secondary teachers struggle to implement this approach within discipline-specific education systems, facing difficulties in coherently aligning the silo curriculums and meeting the obligations of the single-discipline assessment and reporting obligations (Care et al., 2018; Nistor et al., 2018; Venville et al., 2002).

Equally persistent has been a growing disquiet amongst mathematics educators about the apparent ambivalence of the role of mathematics within the integrated STEM education endeavour (Baldinger et al., 2020; English & Kirshner, 2015; Fitzallen, 2015; Kang, 2019; Roehrig et al., 2012; Tran & Nathan, 2010). In recent years the distribution of discipline learning in integrated STEM has emerged as an issue of concern (for example, English, 2016a, 2016b; Maass et al., 2019), and this concern appears to be particularly acute for mathematics. Honey et al. (2014) observed that one STEM discipline usually dominates over the others, and research indicates that the dominant disciplines are usually science and technology (Clark-Wilson & Ahmed, 2009; English, 2016b; Maass et al., 2019; Pang & Good, 2000; Stohlmann, 2018). English (2016b) provides the example of only 16% of 141 papers presented at a STEM education conference in 2014 having a focus on mathematics, as opposed to 45% focusing on science. Further, Baldinger et al. (2020) found that of 4072 articles researching STEM education approaches published in 19 STEM education research related journals from 2013-2018, only 32 described approaches that highlighted mathematics.

. In addition, coverage of mathematics content, when occurring, can be shallow, process driven and misaligned with the coherence of the curriculum structure, or contrived in order to provide an integrated STEM label (Baker & Galanti, 2017; Nathan et al., 2008; Pruet, 2015; Venville et al., 2002). Maintaining the integrity of mathematics curriculum progressions is a recurring issue, especially when faced with student preparation for external standardised testing, leading mathematics teachers at times to retreat from a commitment to integrated STEM and return to discipline-based classes (Bingham, 2016; Kang, 2019; Rogers et al., 2011; Venville et al., 2002). Notably, it has been observed that it may be more challenging to accommodate meaningful curriculum-driven mathematics in an integrated STEM program (Australian Curriculum Assessment and Reporting Authority [ACARA], 2016; Behrend et al., 2014; Clark-Wilson & Ahmed, 2009; Martín-Páez et al., 2019; Rogers et al., 2011; Wang, 2012).

Notwithstanding the numerous STEM education programs implemented and funded by governments and agencies, little progress has been made in establishing a rigorous evaluation regime for STEM education programs and interventions (Department for Education and Skills, 2006; Honey et al., 2014; NSTC Subcommittee on Education, 2008; Simkin & Futch, 2006; Wiswall et al., 2014). The lack of agreed definition of the distinctive elements of a STEM education program, together with lack of clarity of intended learning outcomes (Breiner et al., 2012; LaForce et al., 2016), severely hinder the development of effective rubrics to evaluate the range of interventions that could conceivably fall under the STEM education umbrella (Royal Academy of Engineering, 2016). In particular, evaluations of achievement in mathematics attributable to participation in a STEM education program are scant (Banerjee, 2017; Doig & Jobling, 2019; Gnagey & Lavertu, 2016; Honey et al., 2014) and at best suggest that positive impact on student achievement in mathematics is variable (Banerjee, 2017; Becker & Park, 2011; Bicer & Capraro, 2019; Bicer et al., 2015; Cetin et al., 2015; Gnagey & Lavertu, 2016; Sahin et al., 2015; Wiswall et al., 2014). Behrend et al. (2014) report that mathematics was eventually excepted from an otherwise successful fully integrated model in a high-profile STEM high school due to poor subsequent student performance in college-level mathematics.

1.2. Purpose of this research

STEM education strategies anticipate changes to the status quo to achieve the articulated goals. Specifically, change is envisaged in the way in which curriculum learning is constructed in the component disciplines together with pedagogical change in delivery. While STEM education has been enthusiastically and expansively embraced by politicians and researchers, the response from mathematics teachers and others involved in implementing the STEM education agenda in the school environment has been more muted. This response has largely been sought only as a result of, and is thus limited to, implementation experiences *as part of larger studies* (for example, Cinar et al., 2016; Meyer et al., 2010; Wang et al., 2011; Weinberg & Sample McMeeking, 2017). Thus, it is difficult to see beyond the scope of individual research enquiry to gauge whether the STEM education strategies have stimulated movement towards (or away from) the change envisaged *as a whole*, or simply in response to a *specific* research-driven STEM model or program. Responding to "the multiplicity of school arrangements and learning goals" (Tytler et al., 2016, p. 4) that has developed pursuant to STEM education strategies, this research is unique in seeking to investigate the *landscape* of STEM education for mathematics in NSW, both in terms of *perceptions and experiences* as well as the *mathematics learning* comprised therein, that emerged in response to the NSW STEM strategy. Since the NSW strategy enacts the NSSES in NSW for school education, it is considered the primary enabling strategy in NSW in this research.

The landscape of STEM education in NSW schools developed within the ambit of the NSW strategy, together with the boundaries of the Australian and NSW curriculum framework and educational structure overall. Whilst there are many stakeholders in this landscape, this research focuses on those considered important to the implementation effort for mathematics in secondary schools. These stakeholders are state education regulatory authorities, external advisors and providers of STEM education programs, tertiary educators of preservice mathematics teachers and mathematics teachers themselves, and this research acknowledges the limitations imposed by this choice. To capture the breadth of this landscape and the context within which the NSW STEM education agenda for mathematics evolved, a mixed-methods approach to data collection was adopted, comprising semi-structured interviews, a web survey of mathematics teachers and analysis of key contextual documents. As a result, the response of the regulatory environment was considered from *both* the point of view of the enabling policy documents *as well as* implementation observations of the regulatory officers. This wide-angled overview of insights representing a range of experiences from different vantage points of the STEM education endeavour in NSW allowed for investigation of any divergences and convergences that emerged. A detailed analysis of the nature of mathematics learning implemented in STEM education in NSW provided depth to the overview, and afforded the opportunity to investigate research observations concerning the role of mathematics in STEM education in the local context. Through these dual and complementary investigations, the contours of the STEM landscape for mathematics in NSW emerged. By examining these contours, this research sought to offer insight into the reception and sustainability of STEM education in the mathematics classroom in NSW secondary schools.

STEM education policies are essentially concerned with initiating change to bring about the policy goals. By promoting interdisciplinary or integrated curriculum delivery by way of student-centred approaches, STEM education anticipates both structural change and change on the part of individual teachers by adopting associated pedagogies. Measuring change in educational reform is difficult (McDonnell, 2005) and even more so when the envisaged change is not mandatory nor embedded in the curriculum, as is the case with both the NSSES and the NSW STEM education strategy. To consider structural change, this research takes ideas from the theories of change, a framework proposed by Weiss (1995) in the context of evaluating social programs and reframed purposefully for STEM education programs by Connolly and Seymour (2015). Using these ideas required the identification of causal assumptions inherent in the NSW STEM strategy that would lead to the changes envisaged by the strategy being realised, or, as Connolly and Seymour (2015) explain the relationship: "If I do *x*, then I expect *y* to occur, and *for these reasons*" (p. 1). As is the case with many change programs, causal assumptions underpinning implementation success were not explicitly stated or justified in the NSW STEM strategy. Rather, they were *revealed* by the divergence or convergence of stakeholder understandings and experiences around common concerns *in response to* the strategy. Such divergencies and convergences provided insight into the sustainability of the structural change agenda envisaged by the strategy. Individual teacher change was considered by movement along the continuum described in the 'Levels of Use' framework (Bennett & Anderson, 2018) from the *Concerns Based Adoption Model* (CBAM) (Hall, 1974). This framework guided exploration of what Williams et al. (2016) describe as the "disturbance in the field" (p. 31), as teachers move away from previous entrenched practices to adopt instructional innovation.

Additionally, as a former secondary school mathematics teacher, I was specifically interested in the encounter between mathematics teaching and STEM education and so the ‘loudest voice’ was intentionally given to mathematics teachers via the web survey. Once again, although previous research has referenced perceptions and experiences of mathematics teachers in *specific* STEM education programs or models *as part of larger studies*, this study is unique in focusing on their *overall* perceptions in response to their classroom experiences of *various* STEM education practices as implemented in their schools. In particular, as an indication of change, I was interested in how the experiences of mathematics teachers had both shaped their understanding of the role of mathematics in STEM education and impacted on their classroom teaching.

As explained, the landscape of STEM education for mathematics in NSW considered in this research comprises both the perceptions and experiences of stakeholders involved in mathematics education as well as what mathematics learning *looked like* in STEM education programs implemented in NSW secondary schools. Research has consistently observed that integrated STEM programs include little or no mathematics content and such content favours low skill-level, process driven procedures that do not fulfill the *progression of learning* required by the formal mathematics curriculum documents (Hayward, 2016; Lasa et al., 2020; Margot & Kettler, 2019; Martín-Páez et al., 2019). Particular challenges are also presented for mathematics by tensions between the curriculum documents, manifested by content/standard misalignments in integrated STEM programs (where content required by the program is either below or above the stage or standard level of the students) (Clark-Wilson & Ahmed, 2009; Meyer et al., 2010; Wong, 2018; Wong & Dillon, 2020) and lack of congruency of language and approach for the use of mathematical terms, procedures and techniques across other disciplines involved in the program (Cockcroft, 1982; Leinhardt et al., 1990; Orton & Roper, 2000; Pearson, 2017; Wong & Dillon, 2020). Introducing an analysis of the mathematics learning in STEM education programs implemented in NSW secondary schools allowed this research to investigate these research claims in the NSW context. The analysis also provoked further consideration of the role of mathematics overall in integrated STEM programs in terms of the transactional value to mathematics curriculum learning progressions and the epistemology of STEM education, an area of increased research interest.

No attempt is made in this research to wade into the controversial and murky waters of defining STEM education. Rather, the lack of clarity and understanding of definition itself is a feature of the STEM landscape in NSW. Instead, this research draws on the statements made in the NSW strategy at face-value. It interprets the model of STEM education promoted by the policy and regulatory authorities in NSW as describing the delivery of curriculum learning in all three of the mandatory NSW STEM disciplines (Science, Technology and Mathematics) by means of fully integrated or interdisciplinary units of work (NSW Department of Education, 2016b, 2020b). Furthermore, these units of works represent a collaborative effort between the STEM disciplines and consist of the development and production of a design project (NESA, 2017c). This interpretation (rather than definition) shares key characteristics with many of the models promoted by research in this field (see, for example, English & Kirshner, 2015; Moore & Smith, 2014). In this way the NSW strategy might be considered paradigmatic for the delivery of curriculum learning in secondary school by means of an integrated STEM program or unit of work within a discipline-specific education structure.

1.3. Research questions

Research questions were formulated with two aims in mind. The first was to investigate the understanding and experience of major stakeholders involved in STEM education for mathematics in NSW secondary schools in response to the NSW STEM strategy, together with what mathematics learning in implemented STEM programs looked like. The second aim was to interrogate these findings to identify the implementation assumptions underlying the NSW STEM education strategy and reveal signposts of structural and individual change.

Thus the research questions were formulated as:

1. What is understood and enacted as mathematics teaching and learning within a STEM education model in NSW secondary schools?

2. To what extent does this approach to STEM education represent an effective model of change for mathematics education in NSW secondary schools?

This study was prompted by an apparent tension between statements of STEM education strategy as delivered to the teachers in NSW and the lived reality of the school environment. Although the audience of the NSW strategy is every school in NSW, regardless of student profile, resources or connections, the promise of STEM education appeared accessible only by way of a singular model irrespective of the many factors idiosyncratic to individual schools and the overall structure of the education system. Additionally, the NSSES specifically singles out mathematics as requiring renewed focus, highlighting mathematical thinking as “a fundamental skill that underpins all STEM learning” (Education Council, 2015, p. 8). It was difficult to reconcile this focus with the ambivalence displayed towards mathematics in STEM programs and units of work, nor indeed understand how the limited role of mathematics in STEM would engage and inspire students to further their mathematics education.

By understanding the convergences and/or divergences that emerged between the intentions of the STEM strategies and the realities of implementation efforts across a range of environments, this research sought to contribute to an understanding of how regulatory guidance might be adjusted and realigned so that the affordances of STEM education are accessible to all teachers and students, and the roles and curriculum demands of all STEM disciplines respected and promoted. In doing so, this study supports the call of researchers such as Holmlund et al. (2018), Bryan and Guzey (2020) and Tytler et al. (2016) to move beyond the search for a single, worldwide definition of STEM education, and rather takes a more expansive and pragmatic view. This stance recognises that, although the *aims* of STEM education may be global, the actual *implementation* must adapt to and adopt the unique features of the local environment. This broader stance opens the door to resolving the role of mathematics in STEM education as it moves beyond the singular model promoted in NSW of fully integrated units of work driven by a design project, and indeed allows the profile of each of the disciplines to wax and wane according to the priorities of the local environment. The success of education reforms hinges on the practical mechanisms of implementation required to turn them into “daily practices for teachers (and) school administrators” (Viennet & Pont, 2017, p. 8). By examining the underlying assumptions of a STEM education strategy to account for the messy complexity of the classroom, as well as the responses of individual teachers, strategies and research that enable the promise of STEM education to be delivered in every school may be achieved.

1.4. Structure of this thesis

This thesis is structured in six chapters. Following this chapter, Chapter 2 sets the scene for this research by reviewing relevant literature. STEM education has generated and continues to generate enormous research interest and corresponding literature, and so, after a brief background and history of STEM education, both in the policy setting and in research, the scope of the literature review is confined to mathematics education in STEM education. From this review, four themes emerged which guided the approach to data collection and analysis, as described in the research design and methodology in Chapter 3. Findings from the data collection and analysis are reported in Chapter 4, once again informed by the guiding themes. The penultimate chapter discusses the findings in response to my research questions and Chapter 6 concludes this thesis with an overview of the contribution and limitations of my research, pointing the way towards recommended further research and actions in the regulatory environment to advance the field of STEM education for mathematics.

Chapter 2. Literature Review

Since STEM (Science, Technology, Engineering and Technology)[5] education reforms swept into the global education arena in the 21st century, a vast amount of academic literature has been generated exploring the phenomena from an equally vast number of perspectives. At least four journals dedicated to STEM education have been introduced since 2000[6] , countless conferences held and papers presented. Many definitions, models, frameworks and conceptual arguments have been advanced and, as the field evolves, many questions and concerns raised. Persistent amongst these has been a growing disquiet amongst mathematics educators about role and nature of mathematics education within the conception of STEM education in the school environment, specifically the apparent diminution of the importance of mathematics (Baldinger et al., 2020; Clark-Wilson & Ahmed, 2009; English, 2016b; Maass et al., 2019; Pang & Good, 2000; Stohlmann, 2018). This has created tension, both with the political aims of reform and the implementation experience of mathematics teachers, raising questions about the sustainability of the changes in curriculum delivery and pedagogy envisaged by the STEM education agenda, particularly for mathematics. Whilst these concerns have been voiced by mathematics educators since the inception of STEM education, little progress appears to have been made in resolving this tension.

This chapter reviews the literature on STEM education and integrated STEM education programs, focusing on the experience of mathematics educators in implemented STEM education programs. It begins with an outline of both the political and academic origins of STEM education and continues by identifying difficulties, both professional and structural, that mathematics teachers face in their attempts to implement or participate in a STEM education program within their schools. In doing so, this review provides a platform for the rationale of this study, which aims to

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[5] For a brief yet comprehensive history of the origins of the STEM acronym, see Lyons (2020).

[6] Titles include the International Journal of STEM education (2014), Journal of STEM Education: Innovations and Research (2000), Journal for STEM Education Research (2018) and the European Journal of STEM Education (2016).

contribute to understanding the experience of mathematics education in STEM education programs in NSW secondary school.

2.1. Why STEM and STEM education?

The acronym STEM (Science, Technology, Engineering and Mathematics, appeared in the 1990s as a shorthand way to succinctly describe the range of knowledge and skills widely acknowledged as essential to innovation, growth and global competitiveness in a knowledge economy (Marginson et al., 2013; Sanders, 2009). The term 'knowledge economy' came to prominence in the late twentieth century (Drucker, 1969) as post-industrial nationals shifted from manufacturing-based economies to "economies which are directly based on the production, distribution and use of knowledge and information" (Organisation for Economic Co-operation and Development [OECD], 1996, p. 7). Driven by technology-based products and services and continual innovation, such economies privilege the mathematical, scientific, technological and problem-solving knowledges on which they rely (Marginson et al., 2013; Sanders, 2009). This shift unpins a near global consensus that the development and growth of these knowledges are critical to economic and social prosperity (Chesky & Wolfmeyer, 2015; Guile, 2010; Kenway, 2008). The acronym STEM is now ubiquitous in the public domain, however common usage by the media, industry and politicians[7] alike conceals the complexity of the nexus between education, employment and productivity it has come to represent (National Science Foundation, 2010; Siekmann, 2016).

When talking about STEM education, it is necessary to be mindful of the context in which the term is used. In popular and political usage, STEM education refers simply to education in the disciplines of science, technology, engineering and mathematics. However, among the academic education research community, it has been interpreted as delivering education in the component disciplines using innovative pedagogies (Timms et al., 2018). The STEM education of the political and public arena

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[7] For example, 'STEM skills' (Avery, 2015), 'STEM indicators' (Reading et al., 2015), 'STEM teachers' (Latifi, 2018) or simply 'STEM' (Singhal, 2018)

is tied firmly to economic goals, whereas the STEM education of the education arena is concerned with transforming learning using student-centred pedagogies. The next subsection is concerned with STEM education as understood at policy level. The perspective of the education community follows.

2.1.1. *Policy and strategy responses to STEM education*

With a series of economic reports[8] in the early 2000s forecasting shortfalls in the supply of the STEM-skilled workforce of several nations (Williams, 2011), the role of schools in developing these essential STEM skills came under increasing scrutiny (Ellison & Allen, 2018; Sahlberg, 2010). The need to strengthen science and mathematics education in OECD countries had been recognised since the 1980s (Breiner et al., 2012) as a result of declining secondary student achievement in international benchmark testing[9] together with enrolments in STEM focused tertiary studies (Ainley et al., 2008; European Review, 2009; OECD Global Science Forum, 2006; OCS, 2012a). Reversing these trends became “an almost universal governmental preoccupation” (Marginson et al., 2013, p. 53) and a natural extension of the prevailing neoliberal agenda positioning education as part of the national economic endeavour (Connell, 2013; Moutsios, 2010; Murphy, 2016; Schuck et al., 2018; Smith, 2016). Against this backdrop the term ‘STEM education’, although originally used by the National Science Foundation to refer to tertiary enrolments in the fields of science, technology, engineering and mathematics (Department for Education and Skills, 2004; Kuenzi, 2008), expanded to include K – 12 school education as part of the ‘STEM pipeline’ aimed at increasing the flow of suitably qualified and interested students into the STEM tertiary disciplines. STEM education is now understood to encompass the primary, secondary and tertiary sectors and has become a dominant global policy

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[9] This benchmark testing comprises Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA). Both form part of the Australian National Assessment Program under the Measurement Framework for Schooling in Australia.

discourse, linked intrinsically to other popular discourses such as 21st century skills and innovation (Ellison & Allen, 2018) together with economic prosperity (Denniss, 2018).

Education policies and strategies focusing on improving school education outcomes in the STEM disciplines have been implemented worldwide, across developed and developing nations alike, and share the common aim of improving the number of school leavers with competence in STEM skills, particularly science and mathematics. Although such policies and strategies vary across jurisdictions, they fall broadly into the ‘formal’ and ‘informal’ responses. Formal actions taken by governments impact elements of the overall structure of compulsory schooling, such as mandated curricula and assessment regimes, together with actions aimed at increasing the quantity and quality of STEM teachers. Informal responses, on the other hand, describe programs or activities additional to, but not replacing, formal mandated curricula. Governments have directly or indirectly funded or promoted informal responses, which may be developed or approved by education authorities themselves (for example, the iSTEM syllabus developed externally by a school and approved by NESA as an optional subject in secondary school (NESA, n.d.-a)), or developed in-house by a particular school or by organisations external to schools, both for- and not-for-profit, including government agencies.

For brevity, responses to STEM education in the UK, the US and European Union (EU) countries are overviewed using these categories, whilst that of developing countries and the Australian response are described separately.

2.1.2. Overview of international responses to STEM education

2.1.2.1. The UK, US and EU

In both the UK and the US, the impetus for STEM education policies were high level government reports commissioned to review the national economic agendas, such as the 2002 *SET for Success* (Roberts, 2002) report in the UK and the 2007 *Rising above the Gathering Storm* (National Research Council [NRC], 2007) in the US. In both cases, immediate action was called for amid concerns about the ability of the relevant education systems to deliver adequately skilled graduates and workers in sufficient numbers to vouchsafe a prominent role in the global economy (and associated social prosperity).

In the UK, formal STEM education policies and initiatives (HM Treasury, 2004) included the introduction of rigorous national curricula in mathematics and the sciences together with changes to the structure and level of challenge of external testing (The Parliamentary Office of Science and Technology [POST], 2013). The 2014 report *Vision for science and mathematics education* (The Royal Society Policy Centre) recognised that, despite many inspiring practices in teaching science and mathematics, more needed to be done to place mathematics and science at the heart of the education system to 'ensure the future prosperity of the UK' (The Royal Society Policy Centre, 2014, p. 8). In the US, the *America COMPETES Act* (U.S.C., 2007) sought to support research and development in both STEM and STEM education. The introduction of *Common Core Standards for Mathematics* (2010) and *Science* (2013) was a major achievement, overcoming a highly decentralised and politicised education system. For the first time, a nationwide set of learning standards and definitions of proficiency in mathematics and science was established. A further significant development in formal STEM education in the US has been the rapid growth in publicly funded and self-named specialist STEM High Schools, which aim to promote inclusive access to an advanced curriculum and expert teachers (Erdogan & Stuessy, 2015). In both the UK and the US, substantial effort has been made to upskill existing and out-of-field STEM teachers and attract trainee STEM teachers (House of Commons Committee of Public Accounts, 2018; Maltese et al., 2013) and STEM education remains a strategic priority for both governments (Campisi, 2019, January 9; Committee on STEM Education National Science and Technology Council (CoSTEM), 2018; House of Commons Committee of Public Accounts, 2018).

The majority of EU countries have individually implemented formal STEM education policies and programs, including changes to school curricula aimed at increasing the challenge of selected STEM subjects and emphasising cross-curricular links (European Schoolnet, 2017), for example, changes to the French mathematics curriculum in 2010 (Oliveira & Roberts, 2013). In an overview of STEM education policies in Europe, European Schoolnet (2018) stressed the continued prominence and importance of mathematics education in EU school systems and noted that new methodologies were emerging with the other STEM subjects. However, Galev (2015), investigating the status quo of STEM education in Europe, found that the approach to science education remained theory-oriented and in many European countries STEM educational policies have not provided expected results.

The informal external STEM education sector in the UK has benefitted from increased government funding, with over 600 organisations providing some form of informal STEM programs to schools (Royal Academy of Engineering, 2016). These programs have generally been directed to enhancement and enrichment activities, overwhelmingly focusing on the sciences (Royal Academy of Engineering, 2016; Straw et al., 2011; Tomei et al., 2013), although there have been renewed efforts to promote mathematics focused programs (National Audit Office, 2018). Similarly, US funding led to a rapid rise in the number of informal STEM related education programs, primarily focused on mathematics and science (CoSTEM, 2013; Li et al., 2020), including many provided by federal agencies (Kuenzi, 2008). In both countries, duplication and lack of coordination and rigorous evaluation continue to present challenges in identifying and scaling successful informal STEM education programs and interventions over the long term (Honey et al., 2014; National Audit Office, 2018; NRC, 2011; President’s Council of Advisors in Science and Technology [PCAST], 2010). In the EU, individual countries have funded and/or established agency partnerships with initiatives in the informal STEM sector (European Schoolnet, 2017). Additionally, two umbrella bodies[10] representing the EU ministries of education are funded with aspects of informal STEM education. The European Schoolnet (2018) overview called for national coordination of the “maze of STEM resources” online (p. 21), in addition to the vast number of informal European STEM activities and initiatives (by 2013 there were estimated to have been between 3000 and 5000 informal STEM initiatives in Europe (Durando, 2013)).

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[10] European Schoolnet focuses on evidence-based innovation to teaching and learning whilst InGenius specifically focuses on providing best practice STEM education resources and promoting science education.

2.1.2.2. Developing countries

Although there may appear to be parallel STEM policies worldwide, and indeed the intent may be convergent, STEM programs and initiatives play out differently according to local contexts (Marginson et al., 2013). The economic aims of STEM education initiatives in developing countries focus on developing, rather than advancing, the technological and other skills needed to establish a reliable industry base and access existing technologies (Ismail, 2018; Marginson et al., 2013). Increasing consistent and equitable access across all levels of school education to quality mathematics, science and technology education and improving participation, especially in historically disadvantaged and marginalised populations, is paramount (Marginson et al., 2013). In most cases, government commitment towards the importance of school science and mathematics education is steadfast, and formal initiatives by way of improved curricula and examination regimes, extending the years of compulsory schooling and increasing both the number and qualifications of STEM teachers, are common (Fitzpatrick et al., 2018; Kahn, 2013; Republic of Rwanda Ministry of Education, 2020). Limited funding, infrastructure and political uncertainty have seen both for- and not-for-profit organisations, together with foreign government and industry alliances, providing informal and formal STEM education programs, often in collaboration with local government agencies (Executive Secretariat for Integral Development, 2014; Ismail, 2018; Morales, 2019; Siemens Stiftung, 2020). Such programs provide critical expertise, technology and resources to the local education systems and are often conducted in collaboration with local government agencies (Kärkkäinen & Vincent-Lancrin, 2013).

2.1.3. STEM education in Australia

Australia has a federalist system, with state and territory governments responsible for the delivery and regulation of school education. Since the early 2000s a series of formal nationwide initiatives aimed at improving the school education system overall were introduced, including national professional standards for teachers and principals, a standardised testing program to assess the numeracy and literacy skills of all Australian schoolchildren and a national curriculum (Viennet & Pont, 2017).

In 2015 national strategies specifically dealing with school STEM education were announced, primary amongst which is the *National STEM School Education Strategy 2016-2026* (NSSES) (Education Council, 2015)[11]. The two overall goals of the NSSES are increasing both the STEM knowledge and skills of all Australian school students and the number of students selecting advanced STEM subjects in senior school. At Federal level, actions encompass both formal curriculum initiatives, such as the development of a national digital technologies curriculum, and funding third party program and resource development highly targeted at school mathematics, science and technology education[12]. Responsibilities were allocated to the states and territories under areas of action broadly aligned to the functionality of these goals in their respective school systems. States and territories each introduced their own form of STEM school education strategies (NSW Parliamentary Research Service, 2017; Timms et al., 2018). These strategies featured a strong focus on strengthening STEM teachers' skills, together with providing a wide range of interventions in schools by way of targeted in-school programs, resources and professional support (Timms et al., 2018). As with the UK, US and Europe, a great number of private and institutional providers are active in offering informal STEM programs to schools[13]. The NSSES defines STEM education loosely, acknowledging that it refers both to the teaching of the individual STEM disciplines as well as a cross-disciplinary approach to teaching, leaving considerable scope for interpretation and action to the jurisdictional education authorities, as is appropriate in the Australian federal system. It is within the ambit of the NSSES, together with the boundaries of the Australian curriculum, that landscape of STEM education in NSW schools has developed.

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[11] The NSSES was followed by the *National Innovation and Science Agenda* (Commonwealth Government, 2015) and *Australia's National Science Statement* 2017 (Commonwealth Government, 2017)

[12] For example, Let's Count Maths (The Smith Family, n.d.); Primary Connections and Science by Doing (Australian Academy of Science, n.d.-a, n.d.-b); Digital Technologies Hub (Education Services Australia, n.d.) ; Maths Inside (Commonwealth Australian Maths and Science Partnerships Program, n.d.) .

[13] For example, the STARportal, launched in 2017 and hosted by a federal agency, provides a searchable database of over 650 STEM activities. https://starportal.edu.au/

2.2. STEM education from an education research perspective

2.2.1. *Integrated STEM education*

In education research, STEM education has become associated with some form of integrated teaching and learning experience involving the component disciplines (Blackley & Howell, 2015; Cavalcanti & Mohr-Schroder, 2019; Honey et al., 2014; Larson, 2017; Mohr-Schroeder et al., 2015; Myers & Berkowicz, 2015). Integrated STEM education draws its origins and purpose from the rich research foundations of curriculum integration. Originating in the late 19th century and championed by Dewey (1986) in the early 20th century, curriculum integration promotes learning that moves away from rigid subject-centred traditions to student-centred pedagogies, advocating active learning in 'real-world' contexts (Beane, 1995; Brown & Bousalis, 2018; Dowden, 2011). As the name suggests, curriculum integration involves a departure from single-subject curriculum design to involve students in a learning journey, where subject boundaries are dissolved and "knowledge is called forth in the context of problems, interests, issues, and concerns at hand" (Beane, 1995, p. 616). Integrated STEM education similarly seeks to blur the boundaries between the component disciplines by positioning learning in authentic contexts, where connecting and negotiating different knowledges mirrors practices in business and industry (Breiner et al., 2012; Falloon et al., 2020), often through problem- or project-based approaches (Han et al., 2015; Holmlund et al., 2018; Jacques, 2017; Kelley & Knowles, 2016; Sahin, 2019). Advocates claim that integrated STEM offers a more positive learning experience to students and better supports the transfer and development of conceptual knowledge and skills than a traditional, discipline based curriculum (Berlin, 1994; Stinson et al., 2009). These claims, particularly concerning the transfer of knowledge and development of conceptual understanding, are disputed (Alleman & Brophy, 1991; Benjamin, 2011; Evans, 1999; Larsen-Freeman, 2013; Perkins & Salomon, 1989; Venville et al., 2005), and are thought to be poorly supported by rigorous empirical studies (Berlin & Lee, 2005; Czerniak et al., 1999; Groves et al., 2017; Guzey et al., 2016; Honey et al., 2014).

Despite the longevity of the concept, a lack of common definition or understanding of an integrated curriculum persists (Meyer et al., 2010; Wang et al., 2011; Weinberg & Sample McMeeking, 2017). The umbrella term ‘integrated curriculum’ may mean “interdisciplinary, multidisciplinary, transdisciplinary, thematic, integrated, connected, nested, sequenced, shared, webbed, threaded, immersed, networked, blended, unified, coordinated, and fused” (Czerniak et al., 1999, p. 422). Predictably then, there is little consensus amongst researchers of a conceptual or operational framework for integrated *STEM* education, and it is poorly understood by educators themselves (Breiner et al., 2012; English, 2016b; Holmlund et al., 2018; Martín-Páez et al., 2019; Nadelson et al., 2012; Weinberg & Sample McMeeking, 2017). Integrated STEM education has been referred to variously as a fully integrated, stand-alone meta-discipline (Ejiwale, 2013; Herschbach, 2011; Kelley & Knowles, 2016; Moore & Smith, 2014) or as involving integration between any two or more of the disciplines (Sanders, 2009; Saxton et al., 2014; Vasquez, 2015) or indeed simply using content from one to contextualize concepts in another (Shaughnessy, 2012; Vasquez, 2015; Weinberg & Sample McMeeking, 2017). In a systematic review of 23 studies describing learning and teaching in integrated STEM, Thibaut et al. (2018) identified 11 different approaches.

Although support for connected learning approaches is expressed in various curriculum documents worldwide (ACARA, 2012; Clough & Olson, 2016; European Schoolnet, 2017), replacing subject-specific curricula of STEM subjects with integrated approaches in the compulsory years of schooling remains uncommon, and traditional pedagogies persist (Nistor et al., 2018; Rennie et al., 2013). Further constraints to implementing integrated STEM education in the school environment are considered in the next section, focusing on the experience of mathematics in STEM. Notwithstanding these challenges and the lack of evidence of success in terms of take up of STEM subjects and achievement (Groves et al., 2017), widespread interest in integrated STEM education continues and STEM education remains an emerging field (Honey et al., 2014; Li et al., 2020; Martín-Páez et al., 2019).

2.2.2. Challenges presented by integrated STEM education

2.2.2.1. Lack of classroom-ready implementation models or frameworks

At a fundamental level, absence of a clear, defined model of integration, or research indicating *which* models have enjoyed a widespread implementation success in the school environment and *why*, leaves teachers to rely on their own content knowledge and experience when interpreting an integrated curriculum intervention. Although various conceptual models, frameworks, checklists and essential characteristics of integrated STEM education have been proposed by researchers (Bybee, 2010; Erdogan & Stuessy, 2015; Herschbach, 2011; Kelley & Knowles, 2016; LaForce et al., 2016; Saxton et al., 2014; Treacy & O'Donoghue, 2014; Weld et al., 2015), there are few or no guidelines available to assist teachers in understanding, adapting and implementing in the classroom. Studies have consistently shown that teacher recognition and characterization of what constitutes integration differ from models of integration proposed by researchers and expressed in various educational reform documents (Meyer et al., 2010; Wang et al., 2011; Weinberg & Sample McMeeking, 2017). Commonly, such perceptions take a narrow content identifying approach (Berlin & White, 2012; Meyer et al., 2010; Stinson et al., 2009), varying with the scope of individual teacher content knowledge. Hence integration, when it occurs, may be "piecemeal and idiosyncratic" (Venville et al., 2002, p. 54).

This lack of understanding and clarity surrounding workable implementation models is reflected in the uncertainty surrounding the role of individual subjects within an integrated STEM program (Maass et al., 2019). STEM and science are often used interchangeably, fueling the popular perception that STEM refers to science alone (English, 2016b; OCS, 2014; Timms et al., 2018). In recent years, as STEM has become interpreted as intrinsically involving a design/engineering approach, the role of the technology[14] discipline has become prominent (Doig & Jobling, 2019; Havice et al., 2018; Wells, 2013, 2016). As implementation of an integrated STEM program in the

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[14] Engineering is rarely found as a mandatory subject in the compulsory years of schooling

school environment demands, inter alia, a contribution of resources from each participating discipline in terms of teacher and student class-time, the balance of representation and involvement of each discipline is an important consideration (English, 2016a; Maass et al., 2019). Honey et al. (2014) observed that one STEM discipline usually dominates over the others, and research indicates that it is usually science and technology[15] (Clark-Wilson & Ahmed, 2009; English, 2016b; Maass et al., 2019; Pang & Good, 2000; Stohlmann, 2018). In particular, mathematics rarely, if ever, is the dominant discipline (English, 2016a; Fitzallen, 2015; Maass et al., 2019; Marginson et al., 2013; Martín-Páez et al., 2019). English (2016b) provides the example of only 16% of 141 papers presented at a STEM education conference in 2014 having a focus on mathematics, as opposed to 45% focusing on science. Further, Baldinger et al. (2020) found that of 4072 articles researching STEM education approaches published in 19 STEM education research related journals from 2013-2018, only 32 described approaches that highlighted mathematics.

2.2.2.2. Transfer and development of knowledge

Integrated learning often assumes students will discover connections between learning areas and transfer knowledge from one to the other unaided (Mestre, 2002; Wicklein & Schell, 1995). Transfer of knowledge of mathematics has a long and controversial research history (Evans, 1999; Frade et al., 2009; Wagner, 2003), however, it is generally acknowledged that the transfer of mathematical knowledge is a complex process, far from the spontaneously occurring event assumed (Evans, 1999; Roberts et al., 2007). Considerable skills and active intervention on the part of the educator are required to make connections explicit (Benjamin, 2011; Evans, 1999; Kang, 2019; Kirschner et al., 2006; Mestre, 2002; Perkins & Salomon, 1989; Roorda et al., 2015; Venville et al., 2002), and direct students to the specific learning intended to be transferred (ACARA, 2016; English & Kirshner, 2015; Evans, 1999;

Harwell et al., 2015; Honey et al., 2014). In particular, it cannot be assumed that students will recognise the mathematics inherent in a problem or project beyond a process such as measuring or counting (English, 2016b; Shaughnessy, 2013; Tran & Nathan, 2010). Lack of or inadequate direction on the part of the educator may impede student skill development and learning in one of more of the component disciplines (Honey et al., 2014).

As noted above, design or engineering challenges have become increasingly associated with integrated STEM. The goal of such challenges is the production of an artefact, that is, a working product or prototype. Research indicates that students focus on qualitative processes and aesthetic details, persisting with trial-and-error strategies to achieve this goal, rather than engaging with the underlying mathematics and science (Berland & Steingut, 2016; Berland et al., 2014; Falloon et al., 2020; Kang, 2019; Leonard, 2005; McComas & Burgin, 2020). Other studies have similarly found that, although students might draw upon relevant disciplinary knowledge at the outset of a task, this soon falls away as they focus on the 'how' (for example, how to build something) rather than the 'why' (is this method better than another, why does it work) (Kelley, 2010; Silk & Schunn, 2016; Venville et al., 2005). Indeed, it is further suggested that real-world problems involving "detailed concrete situations that include rich perceptual information" (Nathan & Pearson, 2014, p.24.781.8) may present cognitive overload to students and obfuscate the conceptual framework within which the problem lies, interfering in particular with the recognition of abstract and general mathematical structures (Pearson, 2017; Silk & Schunn, 2016). Thus any learning may become "context bound" (NRC, 2000, p. 236) within that situation.

2.2.2.3. Accessing quality resources

Finding or developing quality curriculum resources for integrated STEM has proven challenging for teachers of all STEM subjects (Guzey et al., 2016; Peterman et al., 2017; Sahin & Top, 2015; Stohlmann et al., 2011). Despite the vast number of resources commercially or freely available[16], mathematics teachers, in particular, have found an equally vast variation in quality, as well as scant attention paid to alignment with curriculum standards and inclusion of mathematics content (Guzey et al., 2016; Stohlmann et al., 2011). Teachers' experiences are borne out by evidence that explicit integration of mathematics concepts is limited in integrated programs, and integrated programs overall address far less mathematics content than that of the other disciplines involved in the programs (English & Kirshner, 2015; Fitzallen, 2015; Kang, 2019; Roehrig et al., 2012; Tran & Nathan, 2010). Coverage of mathematics content, when occurring, can be shallow, process driven and misaligned with the coherence of the mathematics curriculum structure, or contrived in order to provide an integrated STEM label (Baker & Galanti, 2017; Nathan et al., 2008; Pruet, 2015; Venville et al., 2002). Contrary to the assumption that content overlaps accommodating mathematics in integrated learning will be abundant (Boohan, 2016; Frykholm & Glasson, 2005; Turşucu et al., 2017; Venville et al., 2002; Zhang et al., 2015), mathematics teachers have struggled to find curriculum overlaps that are authentic, non-trivial and appropriate to students' stages of learning (Meyer et al., 2010; Nelson & Slavit, 2007; Wong, 2018; Wong & Dillon, 2020). Teachers of other STEM disciplines, as well as resource writers, admit to struggling with including or foregrounding mathematics content beyond simplistic process. Overall, it appears that mathematics is challenging to include in an integrated program (Australian Curriculum Assessment and Reporting Authority [ACARA], 2016; Clark-Wilson & Ahmed, 2009; Martín-Páez et al., 2019; Rogers et al., 2011; Tytler, 2020; Wang, 2012).

When included in integrated STEM programs, typically the mathematics consists of data collection and representation, measurement (including area and volume), calculations (including ratio and percentages), rearranging and substituting into formulas, coordinate geometry and Pythagoras' theorem (Australian Curriculum Assessment and Reporting Authority [ACARA], 2016; Berlin & Lee, 2005; Frykholm & Glasson, 2005; Osborne, 2014; Stohlmann, 2018; Turşucu et al., 2017; Wang, 2012).

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[16] A Google search of the phrase 'math* STEM integrated classroom resources' conducted on February 7, 2021 yielded 50,200,00 results.

These largely process-driven techniques emphasise the applicative aspects of mathematics, reflecting the pragmatic purpose that mathematics serves in other disciplines as a “tool to be used” (Watanabe & Huntley, 1998, p. 21) to achieve a discipline-specific purpose (Osborne, 2014; Wang, 2012). This characterisation of mathematics as a tool in integrated STEM programs highlights the dual nature of mathematics, being both at once “the most fundamental enabling science, underpinning research and innovation in all other areas of natural and physical science, as well as being central to social sciences”(OCS, 2012a, p. 167), as well as a highly developed field of study in its own right, which may or may not lead to immediate practical applications (Clark-Wilson & Ahmed, 2009; Hoyles et al., 2001). Two related concerns have been raised about the selective use of largely application-driven mathematics in integrated STEM, namely disruption of the structure of mathematics learning and the threat of dilution of learning in mathematics the pursuit of a contextualized, authentic education.

The selection of procedures and techniques required for the theme of an integrated program may disrupt learning that has been deliberately structured and sequenced according to the relative cognitive demands of different concepts and tasks in the curriculum (Clark-Wilson & Ahmed, 2009; Czerniak et al., 1999; Herschbach, 2011; Turner & Rowland, 2011; Weinberg & Sample McMeeking, 2017). The *selection and application only* from this very formal learning structure may in reality lead to a disruption of the overall coherence of the subject learning (Clark-Wilson & Ahmed, 2009; Mason, 1996), without understanding or mastery of the underlying concepts (Chalmers et al., 2017; Larson, 2017; Weinberg & Sample McMeeking, 2017). This in turn may result in a learning situation devoid of conceptual understanding, where students, lacking in coherence of the structure of their mathematical knowledge and understanding, resort to ‘guess and check’ methods (Chalmers et al., 2017; Fitzallen, 2015; Mason, 1996; Silk et al., 2010).

Attention has also been drawn to the barriers presented by the demands of a discipline-based curriculum to the development of integrated resources (Kang, 2019; Timms et al., 2018; Venville et al., 2002). This is explored further in 2.2.2.7. Reconciling discipline content with the theme of an integrated program and the demands of a sequenced and outcome driven syllabus is a difficult and lengthy process

(Anderson & Li, 2020; Bissaker, 2014; Clark-Wilson & Ahmed, 2009; Nadelson et al., 2013; Venville et al., 2002). For mathematics teachers, finding immediate and accessible contextual content becomes more difficult with the increasing complexity and abstraction of mathematical concepts as student progress through secondary school (Filcik et al., 2012; Honey et al., 2014; Kelley, 2010; Rogers et al., 2011). Particular challenges are also presented when the mathematics required by other disciplines in an integrated program is out-of-step with the sequencing of the mathematics syllabus (Clark-Wilson & Ahmed, 2009; Meyer et al., 2010). This "content/standard mismatch" (Meyer et al., 2010, p. 162) is compounded by a lack of congruency of language and approach for mathematical terms, procedures and techniques across other disciplines (Cockcroft, 1982; Leinhardt et al., 1990; Orton & Roper, 2000; Pearson, 2017).

Further, mathematics teachers cannot turn to external providers of school STEM resources with confidence. Apart from the sheer volume of resources on offer, very few focus on mathematics. In the United Kingdom, The Royal Academy of Engineering (2016) found that, of the over 600 externally provided STEM programs offered, 41% focus on specialised and general sciences and 13% on mathematics[17]. Additionally, it appears that such programs are not designed for classroom use. Surveying the programs and resources linked on the Australian STARportal[18] website, Timms et al (2018) noted that "The majority of these are extension activities, offered out of school hours, to engage participants who generally have an existing interest and capacity to pay" (p. 14)

2.2.2.4. Teacher challenges

Challenges can be presented by a lack of common perception of integrated STEM among teachers involved in planning and implementing the integrated program. Research suggests that teacher perceptions of STEM integration in secondary schools

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[17] Author's calculations from presented data.

[18] STARportal is an online, searchable platform for service providers, organisations and individuals to provide or access STEM activities and hosted by the Commonwealth Office of the Chief Scientist.

vary amongst the disciplines (Holmlund et al., 2018; Nadelson et al., 2012; Weinberg & Sample McMeeking, 2017). Not surprisingly, each champion learning their own discipline, viewing other disciplines at best as an opportunity to reinforce content in their own field (Meyer et al., 2010; Weinberg & Sample McMeeking, 2017), or at worst as an afterthought (Wang, 2012). Implementing integrated STEM is thought to be easier for science and technology teachers, as those subjects are grounded in real-world contexts and indeed derive knowledge by reference to the physical world (Clark-Wilson & Ahmed, 2009; Lederman & Niess, 1998; Rogers et al., 2011). Mathematics teachers may have a “bigger journey” (Clark-Wilson & Ahmed, 2009, p. 26) to undertake than other STEM teachers in order to champion mathematics in the face of the more obvious real-world rich contexts of other STEM subjects.

Many secondary teachers express anxiety and a lack of confidence in their ability to teach in a STEM environment, perceiving it to involve developing knowledge of the content and standards in subjects they do not teach (Berlin & White, 2010; Nadelson et al., 2013; Shernoff et al., 2017; Weinberg & Sample McMeeking, 2017). At the same time, teachers can lack the depth and breadth of content knowledge needed to make connections, both within their own disciplines and across disciplines (Becker & Park, 2011; Kanadli, 2019; Kelley & Knowles, 2016; Stinson et al., 2009; Weinberg & Sample McMeeking, 2017). When considering the knowledge constraints experienced by STEM teachers, Khalik et al. (2019) point out that most qualified STEM teachers are not equipped to develop interdisciplinary programs situated in real-world contexts that pay equal regard to their STEM-collaborators. They and others (Honey et al., 2014; McComas & Burgin, 2020; Ríordáin et al., 2016; Wong, 2018) observe that the majority of STEM teachers are trained in a single discipline, and that training does not necessarily include either familiarity with real-world applications of their discipline or connections with other disciplines. Mathematics teachers, in particular, need to develop a deeper knowledge of the opportunities afforded by the mathematics content to the entire STEM spectrum (Fitzallen, 2015; Herschbach, 2011; Pruet, 2015).

Integrated learning also requires a fundamental shift in pedagogy away from discipline appropriate strategies to create a collaborative, student-centred learning environment giving differing weight and attention to component disciplines, at times at the expense of the teacher’s own (Clark-Wilson & Ahmed, 2009; Margot & Kettler, 2019; Shernoff et al., 2017). In addition to lacking the pedagogical strategies, many teachers find relinquishing their role as leader and subject expert difficult and unsettling, calling into question their self-perceptions of professional standing and reputation (ACARA, 2016; Czerniak et al., 1999; Honey et al., 2014; Pruet, 2015; Shernoff et al., 2017; Stohlmann et al., 2011). Feelings of inadequacy in terms of content knowledge and pedagogies for integrated STEM can lead to feelings of lack of self-efficacy in teaching in a STEM environment (Nadelson et al., 2012) and possibly resistance to a STEM agenda. An intransience and disconnect have particularly been observed on the part of mathematics teachers' approaches to, and perceptions of, integration and those of teachers from other STEM disciplines and external STEM providers (Nathan & Pearson, 2014; Rogers et al., 2011; Stohlmann et al., 2011; Wang et al., 2011; Weinberg & Sample McMeeking, 2017). Mathematics teachers' concerns about the nature and adequacy of mathematics content in integrated STEM programs have been explored in Section 2.2.2.3. These concerns may also stem from a degree of conflict felt by mathematics teachers between being part of a school-driven STEM agenda whilst at the same time ensuring that curriculum content has been taught in adequate breadth and depth (Chalmers et al., 2017; Kang, 2019; Wang et al., 2011) so that students' academic progress has not become compromised (Clark-Wilson & Ahmed, 2009; Erdogan et al., 2017). These concerns are exacerbated by the need to prepare students for external standardized testing (Becker & Park, 2011; Berlin & White, 2012; Mohr-Schroeder et al., 2015; Shernoff et al., 2017; Wang et al., 2011; Weinberg & Sample McMeeking, 2017). Such concerns have led some mathematics teachers to retreat from a commitment to integrated STEM to return to discipline-based classes (Bingham, 2016; Kang, 2019; Rogers et al., 2011; Venville et al., 2002).

2.2.2.5. The continued need for single discipline instruction

Honey et al. (2014) specifically warn against integrated STEM education replacing formalized learning in each of the individual disciplines, particularly mathematics, noting that in fact integrated learning requires well developed, subject specific expertise to be able to move fluently between different contextualization. The need for separate instruction is not antithetical to integrated education (Berland, 2013; Mason, 1996; The Royal Society Policy Centre, 2014; Treacy & O'Donoghue,

2014) and appears particularly applicable to mathematics because of the nature of the field of knowledge (Honey et al., 2014; Jacques, 2017; Wallace et al., 2001). Indeed, it appears necessary for students to have separate instruction in order to gain the maximum benefit from the integration (Mason, 1996; Pearson, 2017; Sahin et al., 2015; Stohlmann et al., 2012; Treacy & O'Donoghue, 2014; Tytler, 2020), and there are instances of high schools implementing forms of integrated STEM interventions alongside individual discipline teaching using traditional pedagogies (Behrend et al., 2014; Ellison & Allen, 2018; Tytler et al., 2019). Additionally, any benefits from contextualized learning may be illusory if students are not able to also decontextualize knowledge for application to other situations and within the formal disciplinary knowledge structure (Tran & Nathan, 2010). In the Australian context, Marginson et al. (2013) emphasize the importance of "solid programs of study taught by teachers qualified in the specific discipline … particularly in mathematics" (p. 69). in the disciplinary components of STEM.

2.2.2.6. Whole school challenges

Successful implementation of an integrated STEM program or curriculum does not take place in a vacuum and requires substantive whole-school reforms (Bingham, 2016; Czerniak et al., 1999; Hodges et al., 2013; Stohlmann et al., 2011). These reforms need to be spearheaded by strong school leadership committed to the integrated STEM education agenda in order to drive the transformational change necessary (ACARA, 2016; Avery & Reeve, 2013; Clark-Wilson & Ahmed, 2009; Ellison & Allen, 2018; Honey et al., 2014; LaForce et al., 2016). Administrative challenges include block scheduling for delivery of integrated materials as well as common timetable blocks to enable collaboration and team teaching across disciplines (ACARA, 2016; Chalmers et al., 2017; Shernoff et al., 2017). There can be increased demand for concrete resources and technology as well as significant space consideration for construction and storage of project work (Holmlund et al., 2018; Kanadli, 2019; Khalik et al., 2019; Stohlmann et al., 2011). However, the broadening of teachers' content knowledge and pedagogies to include integrated STEM expertise is arguably the key factor to successful implementation (Honey et al., 2014) and significant resources need to be devoted to sustained teacher professional development in integrated STEM (Berlin & White, 2012; Capraro et al., 2016; Erdogan & Bozeman, 2015).

2.2.2.7. Curriculum and structural challenges

National curriculum documents largely remain structured into single-discipline silos and traditional pedagogies associated with these silos persist (Nistor et al., 2018; Rennie et al., 2013), with students progressing vertically ‘upwards’ through subject silos during the compulsory years of schooling. As Care et al. (2018) point out, this discipline-specific focus is consistent across the curriculum/pedagogy/assessment structure of an aligned education system and together form the coherence, or “grammar of schooling” (Venville et al., 2002, p. 77) of the education system. This coherence extends to the organisation and structure of assessment regimes, schools (subject specific timetabling, staff rooms and teachers) and subject specialist teacher training, particularly in secondary education (ACARA, 2016; Khalik et al., 2019; Munro, 2017; Rennie et al., 2013; Thibaut et al., 2018; Weinberg & Sample McMeeking, 2017), as well as large scale accountability assessments (Mockler, 2018; Moss et al., 2019; Nathan & Pearson, 2014; Wallace et al., 2007). This comprehensive, siloed vertical structure creates tension with attempts to integrate horizontally across discipline boundaries (European Schoolnet, 2018; Nadelson & Seifert, 2017; Rennie et al., 2013; Thibaut et al., 2018; Timms et al., 2018). The content/stage misalignments referred to in Section 2.2.2.3, together with incongruencies in language and approaches between mathematics and other disciplines using mathematical techniques (Meyer et al., 2010; Pearson, 2017; Wong & Dillon, 2019), are symptomatic of a discipline-specific curriculum structure in which curriculums are written in isolation (Cockcroft, 1982; Dodd & Bone, 1995; Wong, 2018). Incongruencies in language and approach are explored further in the next paragraph as specific challenges to integrating curriculum documents.

The Australian educational system is characterised as highly aligned and discipline-specific (Isaacs et al., 2015). Reservations have been expressed about the ability of the educational structures, in particular the curriculum documents, to accommodate integrated approaches in general (Creese et al., 2016; Way et al., 2016) and integrated STEM in particular (Timms et al., 2018). Further, the historic orientation of the NSW curriculum towards subject-specific academic rigour and achievement, together with the very highly detailed mathematics curriculum, have steered pedagogical choices away from any form of integrated approaches (Hughes, 2019; Isaacs et al., 2015). Although both the *Australian Curriculum* and the NSW curriculums are under review at the time of writing, there is no indication that the subject-specific structure will be abandoned (ACARA, 2020b; NSW Education Standards Authority, 2020).

At the classroom level, many researchers assume there are many opportunities for collaborative integrated learning in the curriculum documents. Turning to a set of coherent values and concepts, and “common concerns about the nature of truth” (Venville et al., 2002, p. 62) perceived to be shared by mathematics and science, there is an assumption that content overlaps between school mathematics, science and technology are abundant, in particular, mathematics and science (Berlin & Lee, 2005; Boohan, 2016; Dodd & Bone, 1995; Pang & Good, 2000; Turşucu et al., 2017; Venville et al., 1998; Zhang et al., 2015). However, finding curriculum overlaps meaningful to both disciplines has been challenging for teachers (Nelson & Slavit, 2007; Williams et al., 2016; Wong, 2018; Wong & Dillon, 2020) and discipline-based curriculums, such as the *Australian Curriculum,* have been found to present serious barriers to teachers (Kang, 2019).

Lederman and Niess (1998) challenge the assumption of abundant curriculum overlaps, asserting that there is a fundamental epistemological difference between the disciplines, concerns echoed by a small but growing number of researchers such as Clarke (2014), Baldinger et al. (2020), Tytler (2020) and Tytler et al. (2019). Indeed, the latter authors observe that many interdisciplinary (or integrated) programs fail to honour the integrity of knowledge creation in the individual disciplines and “amount instead to an ’epistemic stew’” (p. 53). Whereas knowledge in science and technology is validated empirically by reference to the external world, mathematics is largely self-referential, relying on internal logic structures for validation. This difference is exemplified by the different ways in which mathematics and science interpret equations. In science, an equation lives in and derives meaning from the physical world (Wong, 2017). Variables represent phenomena in the physical world, they are operationalised and “loaded” with a physical meaning (Redish & Kuo, 2015, p. 565), exerting influence over the equation and affecting its interpretation (Koirala & Bowman, 2003). In science, knowledge is created through the interplay of sense-making between the equation and the physical experience. Mathematics, on the other hand, faces no such constraints apart from those imposed by the internal mathematical grammar of the equation (Redish & Kuo, 2015). Variables have no physical presence and their behaviour is determined by mathematical logic - physical meaning is simply of no relevance (Leinhardt et al., 1990). Further, in asserting fundamental similarity between the disciplines, purpose is also overlooked. Osborne (2014) argues that mathematics serves a pragmatic purpose in science, providing science with a structured system of recording and communication and allowing for logical deduction. Science, on the other hand, serves no purpose within mathematics apart from providing ‘real-world’ examples of mathematical techniques and procedures (Frykholm & Glasson, 2005; Wong, 2017). This role is not limited to science (Orton & Roper, 2000). In other words, learning in science is dependent on student understanding and use of skills learnt in mathematics; the converse is not true (Wong, 2018; Wong & Dillon, 2019).

The lack of congruency of language for and approaches to using mathematical terms, procedures and techniques across other disciplines poses specific challenges to both the teaching of identified curriculum overlaps and transfer of knowledge across disciplines (Cockcroft, 1982; Koirala & Bowman, 2003; Leinhardt et al., 1990; Orton & Roper, 2000; Pearson, 2017). Responding to these incongruencies in a UK guide to the language of mathematics in science for secondary science teachers, Boohan (2016) notes the “different purposes, traditions and practices … (leading) … to some differences in the way language is used” (p. 2). Notable differences are apparent in statistics, often suggested as be able to “function as a bridge connecting a part of mathematics with the sciences” (Dierdorp et al., 2014, p. 2). As an example, Boohan (2016) explains, in school science the term ‘range’ to describe the spread of a data set is used to indicate both the highest and lowest values, whereas mathematics it is expressed as the *difference* between these value.

2.3. Achievement in mathematics in STEM education programs

Notwithstanding the numerous STEM education programs implemented and funded by governments and agencies, little progress has been made in establishing a rigorous alternative evaluation regime for STEM education programs and interventions (Department for Education and Skills, 2006; Honey et al., 2014; NSTC Subcommittee on Education, 2008; Simkin & Futch, 2006; Wiswall et al., 2014). The lack of agreed definition of the distinctive elements of a STEM education program, together with lack of clarity of intended learning outcomes (Breiner et al., 2012; LaForce et al., 2016), severely hinder the development of effective rubrics to evaluate the range of interventions that could conceivably fall under the STEM education umbrella (Royal Academy of Engineering, 2016). Nevertheless, some form of evaluation is necessary, both to provide an evidence based to inform program improvement and for accountability (OECD, 2013; UNESCO, 2017). Although the use of single-discipline assessments in evaluating STEM education programs is contentious (Groves et al., 2017; Harwell et al., 2015; Honey et al., 2014), all STEM education policies have as their starting point the aim of improving student achievement in school STEM subjects and participation in STEM careers. Arguably, mathematics acts as the gatekeeper to STEM careers overall, as lack of an adequate level of mathematics skills has been identified as the single biggest barrier to succeeding in post-secondary STEM education (Anderton & Chivers, 2016; PCAST, 2012; Joyce et al., 2017; Loughlin et al., 2015; McMillan & Edwards, 2019; Nicholas et al., 2015; Poladian & Nicholas, 2013). Further, Marginson et al. (2013) argue that “mathematics is the key generic element in developing competence and confidence in science and technology” (p. 70), affirming that science, technology and engineering are each grounded in representations and applications of mathematics (Advisory Committee on Mathematics Education, 2008; English, 2016b; Shaughnessy, 2012).

Evaluations of achievement in mathematics attributable to participation in a STEM education program are scant (Banerjee, 2017; Doig & Jobling, 2019; Gnagey & Lavertu, 2016; Honey et al., 2014; NRC, 2013; Tytler et al., 2019). Those that exist suggest variable impact, although methodological concerns hinder conclusive findings (Banerjee, 2017; Becker & Park, 2011; Cetin et al., 2015; Gnagey & Lavertu, 2016;

Sahin et al., 2015; Wiswall et al., 2014; Young, Adelman, et al., 2011; Young, House, et al., 2011). These concerns surround issues with the many ways in which STEM education can be both defined and delivered and the attribution of student educational outcomes solely to the presence or absence of STEM (or any other) education intervention. Nevertheless, despite these caveats, the research to date suggests that existing STEM programs are resulting in little or no positive impact on mathematics achievement by high school students (Honey et al., 2014; Nathan & Pearson, 2014) and thus are not preparing students to participate in post-secondary STEM studies or careers. In this respect, the experience of the acclaimed High Tech High School in San Diego, California is instructive, where mathematics was separated from the whole-school integration of content model after students' poor performance in college-level mathematics (Behrend et al., 2014).

2.4. STEM as a change initiative in education

STEM education strategies anticipate changes to the way in which curriculum learning is constructed in the component disciplines (Bryan & Guzey, 2020; Nistor et al., 2018) together with pedagogical change in delivery (Margot & Kettler, 2019; Mohr-Schroeder et al., 2015; Murphy et al., 2019). However, as Viennet and Pont (2017) and (Gaziel, 2010) note, implementing educational reform is difficult as it brings into play a complex array of beliefs, interests and motivations on the part of all stakeholders involved in an education system, from politicians and regulators through to school leaders and administrators, teachers and parents (Adams, 2007; Viennet & Pont, 2017). Measuring the impact of education reform has also proved challenging. The nature of the outputs of an education system extend beyond academic benchmarks and are often intangible (Gaziel, 2010) and the OECD (2015) observes that "many education systems have weak or no traditions of evaluating programs and reforms" (p. 167).

Education reform attempts have conventionally proceeded using a 'top down' approach (Adams, 2007; Chunnu-Brayda, 2012; Clement, 2014; Fullan, 2007; McDonnell, 2005). Mandated by policy makers and education regulatory authorities, many education reform initiatives "bypass the classroom" (OECD, 2015, p. 156) and can be insensitive to the local context of schools and teachers (Goodson & Rudd, 2016;

Goodson, 2001). Policy makers are generally unaware of the nature of teaching and learning, together with the everyday work environment of teachers, who may themselves have experienced waves of repetitive, sometimes contradictory reforms (Clement, 2014; Fullan, 2007; Hargreaves & Goodson, 2006). Viennet and Pont (2017) observe that education policies are developed with little consideration of the practical mechanisms of implementation required to turn them into "daily practices for teachers (and) school administrators" (p. 8). Rationale and explanations of the initiatives and changes entailed are often superficial, failing to articulate the underlying assumptions upon which the reform efforts are predicated (Anderson et al., 2015) and how and why the action proposed to address the perceived need will bring about the desired outcome (Viennet & Pont, 2017). Indeed, underlying the lack of detail and justification are assumptions about how teachers learn and change their practices and why they should, inferring that all is required is "some briefing and a few training sessions" (OECD, 2015, p. 157).

2.4.1. The theories of change approach

Connolly and Seymour (2015) suggest that theories of change can provide a useful approach to guiding the implementation of STEM education reform initiatives. Theories of change originated in social theory-based evaluation and explain the process of change by making explicit the causal links between the desired outcomes of an initiative and its implementation (Weiss, 1995). Using theories of change, a change initiative, in its planning stages, makes explicit the assumptions which have guided the choice of a particular strategy or strategies that will be activated in the program implementation (Weiss, 1995). Put simply, theories of change explain the relationship: "If I do x, then I expect y to occur, and *for these reasons*" (Connolly & Seymour, 2015, p. 1). Ideally, a theory of change should be informed by a change theory (Reinholz & Andrews, 2020), the framework of ideas, supported by evidence, around which the initiative is built and which are generalisable beyond a single instance. This evidentiary framework should support the explicit assumptions so that the theory of change demonstrates internal validity, explaining the reasons *how* and *why* a particular program will work within a given context and time and resourcing restraints to achieve desired outcomes, and failure to do so may result in an attempted implementation of a change program that is not based in reality or evidence and thus unsustainable. (Laing & Todd, 2015). When dealing with the complex change, explicit theories of change allow the change agents to identify enabling and disabling factors and take action accordingly (Kezar et al., 2015). Although using theories of change to examine education reforms or interventions is not common, Dyson and Todd (2010) observe that theories of change may be particularly suited to the complexity of schooling and there is some evidence of the acceptance and use of this practice (Connolly & Seymour, 2015; Dancy & Henderson, 2008; Dyson & Todd, 2010; Hunter, 2021)

Connolly and Seymour (2015) examined 9 school-based STEM reform initiatives funded through National Science Foundation STEM programs for evidence of explicit statements of key causal assumptions. They found that these statements were typically understated or undisclosed, and the programs' theories of change were largely attempts to implement a vision of improvement in mathematics and science education. Specifically referring to STEM strategies in undergraduate education, Dancy and Henderson (2008) identify that most STEM reforms place the burden of the intended change on local change agent educators, who are tasked to develop and disseminate materials in the hope that they will be used by other educators. Despite a lack of proven success (Dancy & Henderson, 2008; Henderson et al., 2011), this implementation model of relying on local agents in the hope of dissemination of the STEM initiative has persisted (Connolly & Seymour, 2015; Kezar et al., 2015; Peterson, 2019). This model ignores the influence of the local environments and structures on change efforts against which the local change agent is pitted (Henderson et al., 2010). Further, these local agents responsible for implementation may not themselves recognise the assumptions on which the program is based and around which it is organised. Without an understanding of the factors affecting why the STEM program should work, achieving and sustaining the desired result is put at risk (Connolly & Seymour, 2015).

2.4.2. Teacher change

Whilst theories of change are useful for critiquing the change sought by an overall education reform program, a more nuanced approach is needed to examine perceptions of change in individual teacher behaviour in response to the reform. The

Concerns-Based Adoption Model [CBAM] (Hall, 1974; Hall & Hord, 2015) has been used in research to describe how teachers attempting to implement forms of instructional and curriculum innovation experience the change process (Anderson, 1997; Bennett & Anderson, 2018; George et al., 2013; Hall & Hord, 2015; Loucks-Horsley, 1996; Paramasveran & Nasri, 2018). CBAM recognises that individual change is a highly personal process which takes time, generally about 3–5 years (Loucks-Horsley, 1996), and there are various stages through which an individual progresses along a non-linear continuum. The 'Levels of Use' component of CBAM (Anderson et al., 2019; Bennett & Anderson, 2018; Hall et al., 2006) considers teacher attitudes to implementing change as manifest by usage of classroom practices associated with the innovation. The progressive levels within this framework describe kinds of changes in individual teacher behaviour that may indicate progress towards adopting the innovation. From a starting point of non-use, key implementation related behaviours are proposed, such as seeking to learn more about the proposed innovation, making innovation-informed changes on a regular basis through to complete incorporation into ongoing routine (Bennett & Anderson, 2018). However, Anderson et al. (2019) warn that teachers do not naturally progress on their own beyond "fumbling initial experiences in the classroom" (p. 165) towards routinely using the innovative classroom practices without some form of continued access to pedagogical expertise in the innovation area. This need for continued professional guidance to introduce innovations in classroom practices is considered a key element of success for school improvement reforms (Fullan, 2007; OECD, 2015; Viennet & Pont, 2017).

2.4.3. The teacher's voice in education initiatives

Hunter and Hoong (2017) insist that research in education should speak directly to teacher's practice, including the "messy complexity'" (p. I-77) of the school environment. This complexity encompasses the macro level of the policy and regulatory framework within which secondary schools must operate, through to the micro level of the school environment. Although policy concerns about the "alienation of research from educational practice" (English & Kirshner, 2015, p. 6) are widespread, Cain and Allan (2017) observe that education research remains "largely invisible at the point of use"(p. 12), being mediated first through the filter of education policy prior to reaching the practice of teachers and schools. In this way, research is often used to justify policy decisions which are then delivered as a *fait accompli* to the school environment, without engaging educators in a dialogue where concerns may be heard and addressed, despite educators bearing primary responsibility for implementation success. Failing to engage school-level stakeholders, in particular teachers, in the reform process, as well as lack of on-going engagement and capacity building at the classroom level, has been identified as a major challenge implementing and sustaining school improvement initiatives (Gaziel, 2010; OECD, 2015; Viennet & Pont, 2017; Zajda, 2003).

Similarly, the voices of mathematics and other teachers have largely featured only incidentally in STEM education research and often after participating in a research-driven implementation model. Examples include: in the US, 9 mathematics and 9 biology teachers interviewed after a 3-day workshop conducted by creators of a proposed school STEM program to understand these teachers approaches to curriculum integration, in particular curriculum challenges and obstacles (Weinberg & Sample McMeeking, 2017); again in the US, 22 kindergarten to year 12 teachers, including 5 mathematics teachers, interviewed and asked to identify challenges and perceived supports to conducting integrated STEM education (Shernoff et al., 2017); in turkey, 57 final year pre-service teachers (20 Mathematics and 37 Science) surveyed at the completion of each day of a two-day STEM workshop conducted by the education directorate to elicit their views on STEM in general, how STEM could benefit their students and intended use of STEM techniques in the classroom (Cinar et al., 2016), and in Australia, comments from teachers, including mathematics teachers, concerning their experiences during participation in long-term STEM education interventions in their schools conducted by universities (Tytler, 2020).

2.5. Concluding remarks

Despite the intense and extensive attention focused on STEM education over the past two decades, challenges persist in the inclusion of a curriculum-coherent and conceptually challenging mathematics education within the implementation models in schools. STEM education, as understood in the education environment, appears to be the latest iteration of a curriculum integration model. Notwithstanding the long research history of this model, difficulties faced by teachers in seeking to implement this "persistently problematic curriculum practice at the school and classroom level" (Munro, 2017, p. 36) have not been resolved and, for mathematics teachers, have been thrown into relief by the widespread adoption of a technology/engineering design process (Doig & Jobling, 2019; Havice et al., 2018; Wells, 2013, 2016). This has raised questions about the inherent validity that the widely accepted model of integrated STEM holds for mathematics education and whether genuine standards-linked learning progressions can be accommodated within this model. These concerns sit uneasily with the political and public understanding of STEM education as being simply education in the component disciplines and the goals of STEM reform, in the political arena, of improving achievement in mathematics education.

Whilst it is acknowledged that STEM education, in the education field, is still developing, several constant themes emerged from the literature that speak specifically to mathematics teaching and learning. Definitional confusion, implementation challenges and inconsistency, together with professional challenges and structural misalignment in terms of content/stage mismatch between curriculums, appear to chronically haunt mathematics teachers in their attempts to participate in or initiate an integrated STEM program. These themes guide this study as it explores the experience of mathematics education in STEM education programs in NSW secondary school. The next chapter provides the methodological justification and research process of the study, including the process of data selection, collection and analysis and ethical considerations.

Chapter 3. Methodology

This research sought to investigate the landscape of STEM education for mathematics that developed in NSW secondary schools in response to the NSW STEM strategy. Since the NSW strategy enacts the *National School Stem Education Strategy* (Education Council, 2015) in NSW for school education, it is considered in this research as the primary enabling strategy in NSW. The approach taken was to view STEM education from the perspectives of different groups of stakeholders, each involved in the implementation effort of STEM education in NSW for mathematics, to offer insight into its reception and sustainability in the mathematics classroom. As capturing and analysing these multiple viewpoints was the driving objective, a pragmatic position was adopted using a mixed methods research design with grounded analysis (Charmaz, 2015; Creswell & Plano Clark, 2007). A mixed methods research design combines elements of both qualitative and quantitative research techniques, recognising that both are important and useful in responding to the research purpose (Johnson & Onwuegbuzie, 2004; Tashakkori & Creswell, 2007). The advantages of using both in this research were compelling – qualitative methods would enhance the capture of nuances in understanding and experiences, whilst quantitative data derived from related contextual documents allowed for triangulation or convergent validation (or otherwise) of certain aspects of the qualitative data (Doyle et al., 2009; Johnson & Onwuegbuzie, 2004). Additionally, the inherent flexibility of the mixed methods approach facilitated the use of data collection methods best suited to pursuing this research aim (Tashakkori & Creswell, 2007), within the time and resources constraints of a doctoral thesis (Mason, 2010). The mixed methods research design in this study comprised semi-structured interviews, a web survey and analysis of key contextual documents. Grounded analysis then afforded the opportunity to compare and integrate the qualitative and quantitative data (Fernández, 2005; Lingard et al., 2008) to reach a more comprehensive understanding of the STEM education landscape for mathematics in NSW to respond to the Research Questions:

1. What is understood and enacted as mathematics teaching and learning within a STEM education model in NSW secondary schools?

2. To what extent does this approach to STEM education represent an effective model of change for mathematics education in NSW secondary schools?

From the relevant literature, reviewed in chapter 2, several themes emerged as important to describe the dimensions of enquiry of the Research Questions. These were formulated as the questions appearing in Table 1 and used to guide the rationale and structure within which data were collected and analysed.

Table 1. *Research Questions: themes guiding dimensions of enquiry*

1.	What is STEM education for mathematics?
2.	What does STEM education for mathematics look like in the classroom?
3.	What are the affordances and challenges of STEM education for mathematics?
4.	What are the indicators of change that would signify the sustainability of STEM education for mathematics?

This Chapter presents the research design, together with a discussion of the appropriateness of the mixed method methodology, the grounded analysis approach and the models of change referenced in this study. Each element in the research design is then detailed, including the data source, instrumentation used to collect data, the process of data collection and the approach used to analyse the data

3.1. Research design and methodology

The themes in Table 1 emerged in the literature to describe areas of continuing concern expressed by various, but distinct, categories of participants involved in the realisation of STEM education as a whole, and in particular for mathematics. The first Research Question is addressed by the first three themes. Hence it seeks to investigate the STEM education environment for mathematics in years 7-10, the compulsory years in secondary school of mathematics education in NSW, from the perspectives of different stakeholders involved in the STEM secondary education landscape in NSW. These were state education regulatory authorities, external STEM advisors and providers of STEM programs, tertiary educators of preservice mathematics teachers and mathematics teachers themselves (the reasoning behind the choice of stakeholders is given in Section 3.1.1.). Relevant strategy documents, STEM programs and STEM resources available and being implemented in NSW secondary classrooms were also considered as forming part of the STEM secondary education landscape in NSW. The research design thus sought to explore both the 'top-down' actions of policy makers and agents external to the classroom, and the localised experiences of the 'bottom-up' mathematics classroom environment (Sarason, 1990) in the context of STEM education initiatives. As such it sought to span the multiple realities and complexities experienced by the stakeholder groups in response to STEM education in NSW.

The second research question responds to STEM education as a change initiative in mathematics education by considering the explicit or implicit predictive assumptions inherent in any such initiative (Weiss, 1995), together with the individual change profile of practitioners (in this research, the secondary mathematics teachers). Themes emerging from the data may suggest the validation or otherwise of these assumptions and associated indicators of change (Connolly & Seymour, 2015), or point to new and unforeseen pathways to change. Hence this research takes an inductive approach, with the ultimate emphasis on the emergent, using grounded analysis to inform the procedural aspects of the overall research design and justifying the use of a mixed method approach (Fernández, 2005).

The research purpose was to identify key features in the understandings and experiences of stakeholder groups as they emerged from the data. Taking a grounded approach to analysis, provided the flexibility to integrate and compare across the data sets whilst sustaining focus on the research purpose (Charmaz, 2015; Fernández, 2005). Through this process of "continuous interplay between data collection and analysis" (Goulding, 1998, p. 52), theories explaining the central phenomenon of the study emerge through constant scanning for and investigation of patterns. Grounded theory itself demands an iterative cycle of simultaneous data collection and analysis, continuing until 'saturation' is reached, a point achieved by continuing data collection until no further evidence emerges and theories are confidently 'grounded' in the data (Glaser & Strauss, 1967). However, Mason (2010) observes that "researchers do not have the luxury of continuing the sort of open-ended research that saturation requires" (p. 5), and this is particularly pertinent to doctoral research. Further, Mason (2010) and other authors (see Green & Thorogood, 2018; Guest et al., 2006) suggest that the university procedural requirements relevant to doctoral candidates preclude this exhaustive process, as ethics committees demand, prior to embarking on the data collection process, details such as a list of participants to be interviewed together with evidence of acceptances and the finalised data collection instruments. In these circumstances, it is not possible for researchers to continue the process of rounds of successive participant selection and processes. Revisiting the original set of participants demands from them a considerable time commitment from the participants which might not be readily forthcoming. Additionally, debate continues about determining when saturation is achieved (for example, Jette et al., 2003; Morse, 1994; Morse, 2000), and indeed whether the process may become itself counter-productive, resulting in diminishing value to the emergent theories or concepts (Corbin & Strauss, 2014). Saturation appears to remain a conceptual point in time, rather than a practical construct for framing a robust data set within time and scope (and, at times, funding) constraints, and suggestions abound as to what constitutes a defensible sample size to reach saturation in doctoral research (Mason, 2010).

In terms of this study, sample sizes and data collection instruments were indeed required to be finalised prior to ethics approval. Document analysis, however, did allow for some degree of iteration, as more contextual documents were sourced to quantitatively address emergent views and experiences. Using the set of themes from the literature review (Table 1) to guide the data collection afforded the possibility of triangulation across the qualitative data sets and across certain aspects of the quantitative data sets, a process that Aldiabat and Le Navenec (2018) hold overcomes the time and scope constraints of using grounded theory in the doctoral process. This process of triangulation, which uses multiple sources to investigate the same set of themes and looking for corroboration or convergence, also afforded opportunities for validation (Greene et al., 1989; Johnson & Onwuegbuzie, 2004).

Although it was not possible to conduct cycles of data collection and analysis, even limited applications of grounded theory may hold "enormous potential for theory construction" (Charmaz, 2015, p. 406). As this study aimed to discover the contours of the landscape of STEM education for mathematics in NSW secondary schools, grounded techniques of coding and constant comparison between data sets were used in data analysis. The literature themes (Table 1), which guided construction of the data collection instruments, also served as the starting point for coding qualitative interview data. Patterns emerging were compared across data sets for credibility. Some quantitative data were also coded, but in this case the purpose was to quantify the occurrence of certain information in documents to yield empirical data or simply to locate and compare information across documents.

3.1.1. Choice of stakeholder groups

The STEM secondary education landscape in NSW accommodates many interested parties, from the obvious involvement of education policy and regulatory authorities and educators through to industry groups and not-for-profit organisations (for example, Australian Industry Group, 2015; Education Council, 2018; Engineers Australia, 2018; Reading et al., 2015; The STEM Education Research Centre, 2018), teachers' associations[19] and parents (for example, Australia Children's University, 2017; Federation of Parents and Citizens Associations of New South Wales, 2017; Simoncini, 2018), and continued interest from the media (for example, Baker, 2019; Lambert, 2018; Masters G., 2016; McNally, 2017). As the focus of this research is the implementation experience of STEM education for mathematics in NSW secondary schools in years 7-10, stakeholder groups of interest were selected based on the actual immediate or potential long-term impact of that group on the mathematics classroom teaching and learning experience in NSW secondary schools. As such, they were limited to education policy and regulatory authorities (in NSW, the NSW Department of Education [NSW DoE]) and its regulatory body the NSW Education Standards Authority [NESA]), head teachers of mathematics in schools and secondary classroom

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[19] For example, STEM resources page on the National Science Teachers Association website https://www.nsta.org/stem/ and professional development offered to mathematics teachers in STEM by the Mathematics Association of NSW (MANSW) https://www.mansw.nsw.edu.au/events/category/building-the-m-in-stem

mathematics teachers, tertiary educators of preservice mathematics teachers (tertiary educators), and industry providers of STEM education advice and programs for use in the secondary classroom, both for and not-for-profit (external STEM advisers and external STEM providers). Possible limitations to this research by excluding the perspectives of other stakeholder groups are acknowledged.

3.1.2. Rationale in using a mixed methods design

The overall research aim was guided both by the intention to explore the themes identified in Table 1 as they emerged within the context of the NSW compulsory secondary school mathematics landscape, whilst incorporating the flexibility to capture these perspectives across the range of stakeholders described in Section 3.1.1. Building breadth and depth into the data collection process was essential to achieve the research aim, and so the methods used were driven by this aim to gain as complete an understanding as possible (Creswell & Plano Clark, 2007; Tashakkori & Teddlie, 2003). Additionally, time and resource constraints of doctoral research (Mason, 2010) dictated that the design be guided by pragmatic considerations of practicality, contextual responsiveness and consequentiality (Tashakori & Teddlie, 1998). These considerations led to the convergent-parallel mixed methods design approach taken, whereby qualitative and quantitative data were collected simultaneously and analysed separately before being merged in the interpretation to produce complementary qualitative and quantitative findings (Creswell & Plano Clark, 2007). This mixed methods approach also enhanced the opportunity for triangulation across the data sets (Greene et al., 1989; Tashakori & Teddlie, 1998), and gave depth to the interpretation by allowing the comparison of qualitative observations and quantitative data.

Qualitative data were collected primarily by way of semi-structured interviews. This method was chosen as it allowed exploration of attitudes, beliefs and experiences within the framework of the themes being investigated in the Research Questions (Adams, 2015). Given the time constraints, this method was used to collect data from representatives from the NSW DoE and NESA, external STEM advisers, tertiary educators of preservice mathematics teachers and head teachers of mathematics. A focus of the research was the implementation experience of STEM education in the classroom from mathematics teachers. To increase sample size and reach, a web survey was used to collect data from this stakeholder group (Evans & Mathur, 2018). The web survey yielded both qualitative and quantitative data derived from the structure of the survey questionnaire. Since the use of a mixed methods approach acknowledges interdependencies and tensions that may be found between qualitative and quantitative data sets (Tashakori & Teddlie, 1998), it was important to consider the contextual documents to which the qualitative data responded. As Lingard et al. (2008) observed, this comparison may or may not produce convergent findings, and this tension adds richness to the insights gained. With that aim, quantitative data evidencing the perspectives of the policy and regulatory framework and external providers of STEM programs were included by contextual document analysis. These different modes of collection and analysis are accommodated by grounded theory analysis (Fernández, 2005).

Table 2 overviews the qualitative and quantitative data sources and collection methods applied for each stakeholder group.

Table 2. *Overview of Data Sources and Data Collection Methods*

Policy and regulatory	**Secondary school educators**	**Tertiary educators**	**External advisors and providers**
Intentions of policy/ regulatory environment regarding maths in STEM	Understanding and enactment of STEM in mathematics in secondary schools in NSW	Teacher Educator understanding and approach to mathematics in secondary school STEM	External industry advisors and providers understanding and approach to mathematics in secondary school STEM
Quantitative data			
• Document analysis of publicly available programs and resources for use in secondary school STEM programs for mathematics	• Web survey of secondary classroom mathematics teachers		• Document analysis of publicly available information about programs and resources for use in secondary school STEM
Qualitative data			
• Semi-structured interviews with officers from DoE	• Semi-structured interviews with head teachers of	• Semi-structured interviews with tertiary educators of	• Semi structured interviews with representative

and NESA.	mathematics • Web survey of secondary classroom mathematics teachers	secondary mathematics preservice teachers	officers of external STEM advisors

Validity and consistency of data collection was important to enable triangulation in the analysis process. The themes in Table 1 informed the structure and content of data collection instruments used in the semi-structured interviews together with the web survey questionnaire and the variables investigated in the document analysis. Table 3 maps both the common interview questions (CIQ) (the questions that were asked in all semi-structured interviews – Appendix A) and the web survey questions (WSQ) (Appendix B) with the four major themes. Variables investigated in the document analysis concerned the first two themes.

Table 3. *Common interview questions and web survey questions mapped to themes*

	Theme	**Sub-theme**	**Instrument Reference**
1.	What is STEM education for mathematics?	Stakeholder perspective	CIQ 4, 1 WSQ 4, 6, 29
2.	What does STEM education for mathematics look like?	What is being done in the classroom	CIQ 2, 3, 4 WSQ 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20
3.	Affordances and challenges of STEM education for mathematics	Teachers Teaching resources Students Whole school The curriculum	CIQ 5, 6 WSQ 21, 22, 23, 24, 25, CIQ 3, 4, 7 WSQ 13, 14, 15, 16, 19, 20
4.	Sustainability of STEM education; indicators of change for mathematics teaching and learning	Perceptions Indicators of change	CIQ 8 WSQ 26, 27, 28 ,29

3.1.3. *Privileging mathematics teachers' voices.*

As a former secondary school mathematics teacher, I was specifically interested in the encounter between mathematics teaching and STEM education, and so the 'loudest voice' was intentionally given to mathematics teachers via the web survey. In particular, as an indication of change, I was interested in how the experiences of mathematics teachers had shaped their understanding of the role of mathematics in STEM education and impacted on their classroom teaching of mathematics. In Section 2.4.3, it was argued that the voices of mathematics and other teachers have largely only been sought in reaction to research-driven implemented models of STEM education (for example, Cinar et al., 2016; Shernoff et al., 2017; Tytler, 2020; Weinberg & Sample McMeeking, 2017). My research specifically aimed to give a prominent voice to secondary school mathematics teachers to allow the perspective of the messy complexity of the school environment to inform the dialogue on STEM education in NSW secondary schools.

3.1.4. The lens of policy and change

The National School STEM Education Strategy (Education Council, 2015) (NSSES) and consequent NSW STEM strategy[20] essentially concern change. Successful implementation of an integrated STEM program anticipates changes in the way in which curriculum learning is delivered in the component disciplines. These changes operate at the structural level of the curriculum and whole school environment and also at the level of the individual teacher. However, measuring change in educational reform is difficult (McDonnell, 2005) and even more so when the envisaged change is not mandatory nor embedded in the curriculum, as is the case with both the NSSES and the NSW STEM education strategy. This research takes the position recommended by Lingard and Renshaw (2013) of “critiquing current policies and practices” (p. 27). It considers the implementation of instructional innovation, as envisaged in the NSW STEM strategy, by drawing on ideas from theories of change to examine structural change, together with referencing indicators of individual teacher change suggested in the ‘Levels of Use’ model from the *Concerns Based Adoption Model* (CBAM) (Bennett & Anderson, 2018; Hall, 1974).

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[20] The NSW government did not produce a ‘stand-alone’ document detailing an overall STEM strategy. As it relates to schools, it was published on a websites hosted by the NSW Department of Education and NSW Education Standards Authority.

Theories of change demand that a change initiative should make explicit the assumptions which have guided the choice of a particular strategy or strategies that will be activated in the program implementation (Weiss, 1995). An evidentiary framework should support these assumptions, explaining the reasons how and why a particular program will work within a given context, time and resourcing restraints to achieve desired outcomes (Laing & Todd, 2015). Connolly and Seymour (2015) explain the relationship as: “If I do x, then I expect y to occur, and *for these reasons*” (p. 1). This research sought to understand the validity of the causal assumptions underpinning anticipated implementation success of the NSW STEM strategy for mathematics in secondary schools by investigating the convergence or otherwise of experiences and perspectives from the stakeholders and documents that might emerge from triangulation of the data. A more nuanced approach was needed to examine perceptions of change in individual teacher behaviour in response to the strategy. The ‘Levels of Use’ model from the *Concerns Based Adoption Model* (CBAM) (Bennett & Anderson, 2018; Hall, 1974) (reproduced in Table 4) suggest a range of indicators of change in teacher attitudes and classroom practices in response to innovations.

Table 4. *“Levels of Use and behavioural indicators for that level” (Bennett & Anderson, 2018, p. 626)*

Renewal	User is seeking more effective alternatives to the innovation
Integration	User is making efforts to work with others re the innovation
Refinement	User is making changes to increase outcomes
Routine	Use has established patterns of use: making few changes
Mechanical	Use is using the innovation; makes changes to increase ease of use
Preparation	User has definite plans to begin using the innovation
Orientation	User is taking the initiative to learn more about the innovation
NonUse	User has no interest in learning/taking action

These indicators informed questions in the web survey of mathematics teachers (see Table 5 and Appendix B), such as their perceptions of benefits of STEM education for students and personal professional practice through to demand for, and preferred nature of, professional training in STEM education techniques (Section 4.4).

Although the ‘Levels of Use’ model supposes a continuum, or hierarchy of change, this research sought indicators of change only.

3.2. Procedure

This section verifies the procurement of all necessary approvals and consents, and then considers each data collection method in turn. For each, the rationale behind selecting the method is explained, followed by the description of the data collection instrument used and identification of the target population. The procedure followed is explained together with the approach to data analysis adopted.

3.2.1. Approvals and consents

Ethics approval from the university Human Research Ethics Committee (HREC) and the NSW DoE State Education Research Applications Process (SERAP) were sought and granted on 7 June 2018 (HREC ETH18-2204) and 19 July 2018 (SERAP 2018282) respectively. These approvals are contained in Appendix C. Further consents and approvals as were required by individual stakeholders during the data collection process are described in the relevant data collection method below.

3.2.2. Web survey of secondary school mathematics teachers in NSW

Using a web survey offered the opportunity to reach a wider sample of the target population than face-to-face or telephone interviews, and without barriers presented by gaining access to the target population to administer a ‘pen and paper’ survey (Callegaro et al., 2015). The web survey took the form of a self-administered, voluntary questionnaire, allowing respondents to complete the questions at their own convenience. These features are considered sufficient to ensure voluntary participation and consent (Kılınç & Fırat, 2017). No incentive was offered for participation. Permission was sought and granted from the Mathematics Association of NSW [MANSW], the professional association of school mathematics educators in NSW, to publish the link to the web survey on that association’s closed Facebook™ page. The link was also included once in MANSW’s electronic communication to members. Correspondence confirming this approval, as well as MANSW’s approval of the web survey questions, can be found in Appendix D. To guarantee anonymity, the settings of the web survey itself did not collect Internet Provider addresses and the questionnaire itself did not ask for any personally identifying information.

Web surveys are increasingly being used and accepted in academic research (Evans & Mathur, 2018, p. 855), offering researchers the practical advantages of a speedy and low cost approach to data collection, with built-in time and geographic flexibility (Callegaro et al., 2015; Couper, 2008; Evans & Mathur, 2018; Kılınç & Fırat, 2017). For potential respondents, web surveys are time-saving and convenient, offering convenience in self-paced participation at a time and place of their own choosing (Callegaro et al., 2015). However, the inherent lack of real-time communication between researcher and respondent obviates opportunities for clarification. Conversely, this lack of contact may also be an advantage for the respondent and indeed for the quality of the research overall, as lack of physical proximity removes the risk of researcher bias or coercion during an interview (Kılınç & Fırat, 2017) as well as allowing more free and uninhibited responses (Callegaro et al., 2015). Given the time and resource constraints of the research, the advantages offered by a web survey to collect data from this important stakeholder group were considered to outweigh the disadvantages.

3.2.2.1. The web survey questionnaire

The web survey questionnaire was composed by the researcher and is attached as Appendix B. The questionnaire was written, constructed and published using the commercially available site SurveyMonkey™, used due to built-in construction tools and ease of access and familiarity of the online survey interface to potential respondents (Evans & Mathur, 2018). The web-link to the survey appearing on the MANSW Facebook™ page and email communication was embedded in an invitation to participate from the author and incorporated behind a graphical ‘launch survey’ (Couper, 2008) button generated automatically by the site (see Appendix E). The estimated time to complete the questionnaire was about 15 to 20 minutes. This estimation was based on trials of the questionnaire performed by academic colleagues and proved to be well-over the ‘typical’ time taken by actual respondents of six minutes and 31 seconds[21]. This much shorter response time may reflect a lack of attention by the respondent and hence a lower level of data quality (Callegaro et al., 2015). At the same time, it may reflect the differing concerns of those trialling the questionnaire in terms of grammar, wording and flow of the questions, rather than simply responding to the questions. The questionnaire forming the basis of the web survey was structured into six sections with 29 questions in total across all sections (see Appendix B for the web survey questions). The thematic design of the questionnaire is described in Table 5 below.

Table 5. *Thematic design of web survey questionnaire*

Section	Title	Purpose	Questions
	Introduction	Introduced the researcher, the purpose of the survey and ethical assurances.	
1.	Just a few questions about you as a maths teacher.	Non-identifying descriptive information concerning teaching experience and location of the respondent.	1 - 5
2.	What does STEM education mean?	Respondent' understanding of what STEM education means for maths.	6
3.	STEM education program(s) in your school (past or present).	Information concerning STEM education programs to which the respondent has been exposed.	7 - 10
4.	Your involvement in teaching maths in a STEM program.	Information concerning STEM education programs involving maths with which the respondent has been involved.	11 - 20
5.	The benefits and challenges in using STEM education to teach maths.	Respondent's opinion of the benefits and challenges of teaching maths in a STEM environment, for both teachers and students.	21-25
6.	Professional development for teaching maths in a STEM environment	Respondent's opinion on the most effective professional development for maths teachers wanting to teach maths in a STEM environment.	26-28
	End comment	Respondent provides any other thoughts he or she may have about STEM education in maths.	29

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[21] data supplied by SurveyMonkey™

In sections 1 to 4, only one response to each question was allowed, including a participant supplied response. However, the majority of questions in sections 5 and 6 (questions 21 to 29) followed a ‘response with categories’ framework. This gave the respondent a number of options to choose from, together with a limited option (500 to 100 characters) to supply a self-generated answer. The limited open-response category was designed to overcome, to an extent, the inability of respondents to ask questions or request clarification (Kılınç & Fırat, 2017; Saris & Gallhofer, 2014). Questions allowing one response only (multiple choice type questions) and those allowing more than one choice (check box type questions) were fairly evenly distributed, with 14 and 12 respectively of such question-types.

The number of category options offered to respondents varied with the nature of the question from three to seven, inclusive of both ‘information type’ and ‘opinion type’ questions. A ‘none of the above’ option was not offered in any question, in an effort to force respondents to thoughtfully select or compose an answer or answers (Couper, 2008). Questions which did not allow either elaboration nor multiple answers were primarily concerned with respondent demographic information (three of five questions) or ‘Yes/No’ responses at the beginning of sections 4 and 5. In these latter cases, a ‘No’ response triggered a built-in logic branch, advancing the respondent to a later section or to the end of the questionnaire. Branch logic was built into the structure of the survey on four occasions to ensure that respondents were filtered through the survey according to individual experience relevant to a set of questions. There were also two free response questions with an unlimited character count (questions 16 and 29). Apart from these two questions, every question required a response before progressing to the next question and there was no facility for the respondent to save their progress and resume the survey at a later date. A progress bar was included in the design.

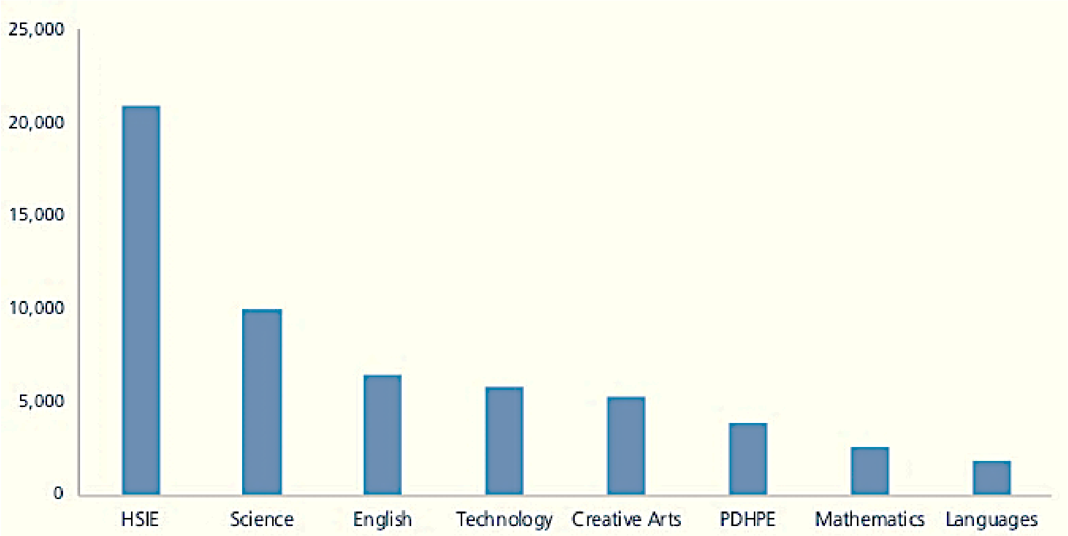
Construction of the questionnaire forming the basis of the web survey was informed both by the need to ensure overall validity by maintaining consistency with the themes, together with issues raised from a review of the literature concerning web surveys. Such issues drew attention to content and wording, researcher and sponsor identity, disclosure of the purpose of the survey and how the data will be used (Evans

& Mathur, 2018), as well as consent, privacy and anonymity concerns (Kılınç & Fırat, 2017) and question flow and saliency (Callegaro et al., 2015). Length of time expected to complete the survey was a particularly important issue (Evans & Mathur, 2018), invoking the challenge of balancing a realistic completion time with the need to collect data that are both sufficient and valid, whilst maintaining the respondent's attention to do so.

3.2.2.2. Target population and sample size.

The target stakeholder group was secondary school mathematics teachers in NSW. Information about the number of such teachers in NSW is not easily available. Figure 1 below is taken from the *Workforce profile of the NSW teaching profession 2017* (Centre for Education Statistics and Evaluation, 2020) (CESE) and shows that, as of 2017, there were approximately 2,000 teachers accredited with the NSW Education Standards Authority (NESA) to teach mathematics as the Key Learning Area (KLA).

Figure 1. *Secondary school teachers accredited with the NSW Education Standards Authority (NESA) as of 2017 by Key Learning Area specialisation. Sourced from CESE (2020, p. 52).*



Accreditation as of 2017 was compulsory only for teachers who, since 2004, had either entered the workforce or returned from an absence of five years or more (CESE, 2020, p. 40). Since January 2018 accreditation with NESA has been required of all teachers in NSW schools (NESA, 2018b). In March 2019 NESA accreditation records show that 3529 teachers have been accredited as secondary mathematics teachers in NSW[22]. These figures must be read with caution. Not only is the accreditation process ongoing, but the data record subjects that an individual teacher is accredited to teach and does not exclude double counting, where teachers are eligible to teach more than one subject (as may be the case with mathematics teachers who are also eligible to teach the Science KLA) (CESE, 2020). Also, this does not include teachers of mathematics who are teaching out-of-field, estimated at about 20% of mathematics teachers Australia-wide (O'Connor & Thomas, 2018; Weldon, 2015). Given the possible inaccuracy and ambiguity of these figures, it was not possible to estimate an overall target population for the web survey. Additionally, although the survey was distributed via the MANSW Facebook™ page, the membership of MANSW cannot be used as to estimate target population size. In addition to individual memberships, a school membership for MANSW can be purchased to include all mathematics teachers employed at that school and MANSW membership records do not account for these individual teachers.

The focus of the survey was to collect data concerning mathematics teachers' professional experience with, and understanding of, STEM, and so data such as gender preference, age or level of accredited proficiency with NESA, type of employment (such as fulltime, part-time or casual), or out-of-field teaching, were not collected. Maintaining this focus meant that the target audience formed, for the purposes of the survey, a relatively homogeneous group defined by their work-life experience. Since the survey sought responses confined to matters directly affecting them as members of the group of secondary mathematics teachers in NSW only, rather than matters extraneous to membership of that group, such responses could be considered representative of that group (Leslie, 1972). Furthermore, since the purpose of the survey was to collect information about perceptions and experience, rather than testing preconceived propositions or hypotheses, a sample size of about 20

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[22] This data were obtained from the Research, Data and Analysis unit of NESA pursuant to a Research Application process on March 7, 2019.

– 30 was considered sufficient to satisfy the purpose of grounded theory analysis (Mason, 2010; Nulty, 2008; Thomson, 2010).

The advantages of using Facebook™ to recruit participants for research studies lie in the low cost of this method and its particular effectiveness in recruiting 'hard-to-reach' or specific demographic populations (Baltar & Brunet, 2012; Ramo & Prochaska, 2012). At the same time, concerns can be expressed about the representativeness of samples (Ramo & Prochaska, 2012), particularly whether there is inherently an upfront sample bias in recruiting from Facebook™ (Kapp et al., 2013). Although in some target populations sampling may be skewed towards respondents with access to a web platform, in the Australian context that possible bias has been largely removed, due to the high level of household use of the internet[23] and the necessary use of the internet within NSW schools[24].

3.2.2.3. The web survey process.

The invitation to participate in the web survey was first posted on the MANSW Facebook™ page on Friday, August 24, 2018. The timing of the publication was dictated by the school reporting administrative timetable published by NESA (NESA, 2018) and associated reporting obligations incumbent upon secondary schools towards the end of August each year. This was followed with a reminder on September 19, 2018, which coincided with a reminder in the MANSW email communication to members. Research suggests that there are diminishing returns on additional reminders after the first or second (Couper, 2008). Altogether 66 responses were received, with the peaks of 30 and 11 responses being attracted immediately after the first posting and the reminder respectively. Although the survey was kept open over the summer vacation period until February 2019, no further responses were

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[23] As of 2017, 86% of Australian households have access to the internet at home (Australian Bureau of Statistics, 2018).

[24] Within the school environment, every NSW school has a school website and all syllabuses published since 2017 by NESA are 'interactive e-syllabuses' to allow continuous update (NSW Education Standards Authority, 2018a).

received after November 2018. Data collected from the web survey were downloaded from the SurveyMonkey™ website in March 2019.

3.2.2.4. Survey participation.

The nature of participation by school location, school sector and years of mathematics teaching experience is shown in Table 6.

Table 6. *Survey participation by school location, school sector and years of experience teaching mathematics*

Participation by school location			
Rural NSW	Regional NSW	Metropolitan Sydney	
11%	24%	65%	
Participation by school sector			
Catholic	Independent	Public	
7.6%	45%	47%	
Participation by years of experience of teaching mathematics			
Less than 1 year	1 to 5 years	5 to 10 years	10 years plus
8%	21%	21%	50%

3.2.2.5. The approach to data analysis

The packages of downloadable data provided by SurveyMonkey™ were utilised for analysis, in conjunction with the online analysis tools available.

- Individual responses grouped by question (“responses by question”).
- Individual responses grouped by respondent (“responses by individual”),
- All responses per question in an Excel spreadsheet (“response spreadsheet’).

Branch logic had been built into the structure of the web survey, resulting in different numbers of respondents throughout. Each respondent was tracked using the response spreadsheet to determine the numbers of respondents progressing via the branch logic triggers and the numbers of respondents who dropped out, and at which question. This enabled participation rates per question to be calculated. From the 66 respondents**,** 53 progressed to completion, giving an overall response rate of 80%. Table 7 records the response rate of individual questions, taking into account the branch logic built into the survey. From this it can be seen that in all but two questions, the response rate from eligible respondents was 100%.

Table 7. *Web survey response rate of individual questions.*

Question	Potential respondents	Actual Respondents	Dropouts	Participation rate
1	66	66	0	100%
2	66	66	0	100%
3	66	66	0	100%
4	66	66	0	100%
5	66	66	5	100%
6	61	61	1	100%
7[25]	60	60	1	100%
8	35	35	0	100%
9	35	35	0	100%
10	35	35	0	100%
11[1]	35	35	0	100%
12[1]	15	15	0	100%
13	11	11	0	100%
14	11	11	0	100%
15	15	14	1[26]	93%
16[27]	14	12	OPTIONAL	86%
17	14	14	0	100%
18	14	14	0	100%
19	14	14	0	100%
20	5	5	0	100%
21	52	48	4[28]	92%
22	48	48	0	100%
23	48	48	0	100%
24	48	48	0	100%
25	48	48	1	100%
26	47	47	0	100%
27	47	47	0	100%
28	47	47	0	100%
29[3]	53	11	OPTIONAL	21%
Total			13[29]	

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[25] branch logic triggered which advanced participants to continue the survey having ‘skipped’ a number of questions.

[26] This respondent had been directed by the branch logic to re-join the survey at question 15 but did not return to the survey.

[27] optional free response questions.

[28] These respondents had been directed by the branch logic to re-join the survey at question 21 but did not return to the survey.

[29] at Question 29, 6 participants who had redirected from question 7 via the branch logic had the option of re-joining the survey. There were 11 responses to Question 29, which was optional. It is not known if these 6 responded to Question 11 or simply left the survey after Question 7.

Table 3 lists the web survey questions responding to the major themes of this research. This grouping of questions was used to report the findings, using the hyperlink tool to individual responses to explore the opportunities provided by free response. Respondents have been anonymised and are referred to with the prefix 'R' followed by a number signifying the order in which the responses were received. For example, R34 refers to the 34th respondent to the survey.

3.2.3. Document analysis

Document analysis was utilised in this study for the purposes of triangulation of the data. In the context of the research, it was considered important to provide empirical data corroborating or elaborating on stakeholder perceptions of the implementation of STEM education policies for mathematics collected by the other methods included in the research design (Bowen, 2009). Since documents remain relatively stable over time, document analysis is particularly suited to investigating policy implementation and progress (Wach & Ward, 2013) in contrast to differing nuances of policy statements across media platforms.

3.2.3.1. Document selection.

Selection of authentic and credible documents is critical for validity of this process (Wach & Ward, 2013). Criteria for selection of the documents described in Table 2 were:

- Publicly available programs and resources produced or published in the policy or regulatory environment for use in secondary school STEM programs for mathematics, and
- Publicly available information about programs and resources produced or published by external providers of secondary STEM programs for use in secondary school STEM.

Documents satisfying the first criteria were published on websites hosted by either the NSW DoE or NESA. From the NSW DoE 'STEM-NSW' website (now defunct)[30], the programs of 27 Stage 4 (years 7 and 8) STEM projects were downloaded for analysis. These programs were produced pursuant to participation in the NSW DoE 2015 Stage 4 Integrated STEM Project ('STEM Project')(NSW DoE, 2016c). Participation in the STEM Project required each school to develop an 'individual, interdisciplinary approach to teaching Science, Technology, Engineering and Mathematics'(NSW DoE, 2016c). The STEM Projects were presented at the Secondary Schools STEM Showcase in June 2016 and the STEM Project programs were found under the 'Teaching & Learning STEM' tab on the website (now defunct)[31]. From the NESA website, the wording of the 'STEM SUPPORT' page (NESA, 2017c) was considered and the three stage 4 sample STEM Units downloaded (NESA, 2017c), along with the *Mathematics STEM Pathway for Stage 5* ('STEM Pathway') (NESA, 2017b) and the *Mathematics Advanced STEM Pathway* ('STEM Pathway Advanced') (NESA, 2017a) (stage 5 refers to years 9 and 10). In addition, the NSW Year 7-10 Mathematics and Science syllabuses for the Australian Curriculum (Board of Studies NSW, 2012a, 2012b) were purchased from the NESA online shop for use in analysis. Together, these documents, being either produced and published pursuant to a NSW DoE program or developed and trialled in schools by NESA, for either mandatory (in the cases of the Mathematics and Science syllabuses) or optional (in the case of the STEM Units, STEM Pathway and STEM Pathway Advanced) implementation in NSW secondary schools, are considered statements of 'policy in action' (Wach & Ward, 2013, p. 2) apropos NSW STEM education policy. Indeed, the STEM Projects are referred to by the NSW DoE as illustrations of STEM practice and resources, available for teachers 'to use and implement in schools' (NSW DoE, 2018, para 5) and aimed at improving the teaching of the STEM subjects in NSW schools (NSW DoE, 2016a, 2017).

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[30] https://web.archive.org/web/20190329154328/http://stem-nsw.com.au/

[31] https://web.archive.org/web/20190329162903/http://stem-nsw.com.au/teaching-stem/stage-4-stem-projects

Second criteria documents are from the STARportal[32], an online, searchable platform for service providers, organisations and individuals to provide or access STEM activities. Validity in this case comes from the hosting of the web-based directory by the Commonwealth Office of the Chief Scientist, notwithstanding the disclaimers of the providers of the platform, The Institution of Engineers Australia[33].

3.2.3.2. The approach to data analysis.

Each of the three sources of documents is considered in turn.

A. NSW DoE STEM Project programs.

Variables of interest in the STEM Project programs were:

- the outcomes selected by the participating schools from the NSW K – 10 Mathematics Syllabus (“outcomes”) for inclusion in the STEM Project together with the learning activities attributed to each outcome;
- the structure of the STEM Project, including duration, participation by students and subject teachers (combinations of two or three from each of mathematics, science, technology and PDHPE) and contribution of class time from the participating subject areas to the STEM Project via the timetable;
- the form of overall STEM Project assessment, in particular the inclusion and form of assessment of the outcomes, and

Where absent, these details were obtained from a supplementary document prepared by the NSW DoE, “*Integrated STEM Stage 4 project - summary of school project details*” [34].

Data concerning the first variable were recorded in an Excel spreadsheet, and frequencies and associated percentages calculated. Activities attributed to each

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[32] https://starportal.edu.au/find-activity/1/. This site is hosted by the Commonwealth Office of the Chief Scientist

[33] https://starportal.edu.au/terms-of-use

[34] https://web.archive.org/web/20190329162903/http://www.stem-nsw.com.au/teaching-stem/stage-4-stem-projects

outcome were captured via coding for each outcome activity in qualitative data analysis software (in this research, NVivo™). A separate Excel spreadsheet recorded the STEM Project program structure variables and assessment data, supplemented by coding the STEM Project programs within NVivo™.

The purpose of coding activities attributed to outcomes was to record the student learning activities carried out to satisfy the syllabus requirements of the outcome. The outcomes for each subject involved in the STEM Project were recorded at the beginning of the programs in a table and the remainder of each STEM Project program described the teaching and learning activities for the students throughout the program. Codes were created in NVivo™ for every Stage 4 outcome in the Mathematics syllabus and each program was coded for appearance of each outcome and activity attributed to that outcome. At times the description of an activity did not align in terms of content to the aligned syllabus description and might be presumed as being a typographical error in the program. To capture these mis-descriptions, two separate codes were created, one for the case where the correct outcome had been included in the list of outcomes provided at the introduction to the program ('Incorrect outcome (in program)') and the other for cases when the correct outcome had not been included in the program outcomes at all ('Incorrect outcome (not in program) '). In such cases the outcome attributed by the program was coded along with relevant additional code.

Some activities attributed to mathematics outcomes were explained in considerable depth to reveal the alignment with the syllabus outcome content, whereas others appeared to touch on the outcome content only briefly or only concerned parts of the outcome content. Two interpretations of these latter cases were considered. Firstly, that the STEM Project was intended to introduce students to the range of mathematics activities that are connected to and comprised within other content areas which may appear dominant in the STEM Project, thus demonstrating the relevance, application and connectedness of their learning in mathematics, rather than representing a content learning experience. Secondly, that the scope of the STEM Project activities did not allow for exploration of the full scope of the mathematics outcomes content. A program document functions both to record how syllabus requirements are met as well as reflecting school priorities, values and initiative (NESA, n.d.-b) and is not possible to capture the intention of the program creators. Where the activity did not, on the face of the document, appear to encompass the scope of the outcome content, the description of the activity along the continuum of learning prescribed by the Mathematics syllabus was considered to ascertain if this limited scope was in fact attributable to an outcome in an earlier stage of the syllabus, and not describing the additional content required in the stage 4 continuum. In such cases the activities were coded both with the program attributed outcome as well as the relevant earlier stage outcome.

The unit of coding was a phrase, sentence or paragraph, as was appropriate to an activity. For example, an activity associated with only one outcome was coded by whole sentence or paragraph. When there was a combination of outcomes involved in an activity, only a phrase pertaining to an outcome might be coded (Appendix L). As an example, the activities “Students to determine the area of the block needed to construct their cars” and “Students will learn or use prior knowledge to calculate the areas of two dimensional shapes. Students will use areas to solve related problems is of fundamental importance in many everyday situations, such as carpeting a floor” were coded to the outcome MA4-13MG “uses formulas to calculate the areas of quadrilateral and circles, and converts between units of area” (Board of Studies NSW, 2012a).

An observation arising from the literature review concerned the lived classroom experience of enacting of STEM education involving mathematics. In particular, the capacity of an integrated STEM program to satisfy both the scope and depth of syllabus content (Chalmers et al., 2017; Mason, 1996) together with the availability of resources explicitly aligned to the syllabus (Guzey et al., 2016; Stohlmann et al., 2011) were questioned. It is recognised that a learning program can only capture the written intention of the creator. It is a “planned learning experience” (NESA, n.d.-b, p. para. 2), written prior to the events of the classroom and conforming to stylistic and content requirements as well as space limitations. As such it is a two-dimensional representation of what the creators foresee will happen rather than an ex post facto description of what actually happened and the success or otherwise of the learning experience. Thus, this process of analysis is only able to capture the intention of the program writers that activities attributed to syllabus outcomes would be suitable and successful in terms of the teaching and learning experience associated with that outcome.

B. NESA Stage 4 STEM Units.

These units have been developed and trialled by NESA for use in NSW secondary schools. They were investigated for the purpose of triangulation with the STEM Project programs in terms of mathematics syllabus outcomes and associated activities and thus were recorded and analysed in the same manner. As sample units, limited information about program structure and assessment was available and so it was not possible to interrogate the documents to the same extent as the STEM Project programs.

C. NESA STEM Pathway and STEM Advanced Pathway.

The STEM Pathway and STEM Advanced Pathway were selected as they provide a strong perspective from the curriculum authority on the delivery of STEM education for mathematics in NSW within the curriculum context. Both represent alternative pathways through the Mathematics syllabus for stage 5 (years 9 and 10) and the focus of analysis was curriculum content and mode of delivery. As these programs apply to a later stage, triangulation with the STEM Project programs was not possible.

D. NESA Mathematics syllabus and Science syllabus.

The purpose of analysing the Mathematics and Science syllabuses was to identify outcomes and content which suggested a connection of learning, or match, between those subject areas in those particular stages. The syllabuses were also investigated for ‘mismatches’, where the outcome content for one subject requires knowledge and skills from another which are beyond the stage content of that other subject. This has been identified as a possible impediment to fulfilling multiple syllabus requirements in integrated STEM programs (Chalmers et al., 2017; Meyer et al., 2010). Reference was also made to a series of mathematics and science textbooks in use in NSW secondary schools to provide examples of classroom activities aligned to the syllabus outcomes.

E. External STEM provider information appearing on the STARportal.

This online, searchable platform provides information about STEM activities offered to schools by external providers. Standardised information about each listing is provided, together with a brief description by the provider. As of July 2019, 638 activities were listed on the STARportal by 286 providers[35]. Two searches were conducted in 24 hours using the filters set out in Table 8 below. The first search yielded 79 results and the second 36.

Table 8. *Search filters used for STARportal searches July 2019*

Search 1	**Search 2**
Location: NSW	Location: NSW
Distance (km): 100 kms	Distance (km): 100 kms
Area of interest: Mathematics	Area of interest: Mathematics
Activity reach: NSW	Activity reach: NSW
All types of programs	All types of programs
Ages: boxes ticked for all of years 7, 8, 9 and 10	Ages: Secondary (there is a separate category for senior secondary)

After discarding the 21 repeated activities in the second search there were 92 activities overall captured by these two searches. The data were then cleaned to focus on activities suitable for in-school classroom use, leaving 73 activities. Standard details provided for each activity were recorded in a spreadsheet, together with information ascertaining whether the focus was on mathematics (regardless of its categorisation via the search filters). Provider websites were visited to gain this information, where available. The mathematics focus could be singular or combined with another. If solely mathematics, the focus was obvious (for example, a mathematics competition). If there was a combined focus, a meaningful focus was taken to be those which explicitly described the mathematics component in the same manner as other components and/or provided specific reference to components of, or curriculum mapping of

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[35] Email from the STARPortal Team March 13, 2019

mathematics content to, the Australian Curriculum for Mathematics. A background in mathematics or mathematics teaching on the part of the creators of the activity or the presenters was also considered important.

3.2.4. Semi-Structured interviews

This study took a semi-structured approach to interviewing. An 'open-ended interview guide' method (Johnson & Turner, 2010, p. 305) was adopted, whereby, although participants were asked the same set of questions (Appendix A), the sequencing could be adjusted with the flow of the interview. The interview questions, informed by the themes of this research (Table 3), were open-ended and broadly stated (Appendix A). For example, the participants were asked their opinion about the essential characteristics of STEM education. This afforded participants the opportunity to respond at length and in detail from individual stakeholder perspectives and experiences. This broad but consistent frame of questioning also affording the researcher the opportunity to probe for clarification and elaboration. This was useful to provide context to how perspectives had been shaped by stakeholder group experience and position within the STEM education environment. The interviews varied in length between 40 minutes and one hour and a half. Recordings were uploaded onto the researcher's laptop before being transcribed either by the researcher or an online commercial transcription service. Respondents were anonymised and are referred to with a prefix corresponding to their stakeholder group, followed by a number signifying the order in which the interviews were conducted for that group. The prefixes used are 'REG' for the policy and regulatory group, 'HT' for the head teachers of mathematics, 'TE' for the tertiary educators of preservice mathematics teachers and 'ESA' for external STEM advisors of NSW secondary schools. There was no alignment between the external STEM advisors interviewed and the analysis of external providers of STEM programs on the STARportal site (Section 3.2.3.2.E).

3.2.4.1. Interview questions.

A set of eight common interview questions (CIQ) formed the basis for every interview (Appendix A). The CIQ were composed by the researcher, working from the four major themes. The mapping of the CIQ against the themes is shown in Table 3. Each CIQ was applicable to the role and stakeholder group of the interviewee, however the differing roles and responsibilities relevant to the particular stakeholder group of the interviewee allowed informed additional, more nuanced questions applicable to that role and responsibilities.

3.2.4.2. Target population and sample size.

The target interview populations were defined by the nature of each stakeholder group. For the policy and regulatory environment, the target population was limited, comprising officers from the DoE and NESA involved in STEM mathematics education or programs. Three officers participated, including at least one from each authority. There are 13 tertiary institutions in NSW offering secondary mathematics teacher training[36]. Of these, four responded to an invitation to participate – three in the metropolitan area of Sydney and one regional. The sponsoring university was not approached.

The population of the stakeholder group comprising external providers of STEM programs for secondary schools is less easily defined. The only comprehensive listing of external providers to the secondary school STEM education marketplace overall appears on the STARPortal[37]. In March 2019, 286 providers were listed on the portal[38], ranging from not-for-profit organisations, such as the Australian Mathematics Trust, through to commercial providers of all sizes, such as Robofun and Robert Bosch (Australia) Pty Ltd. The external STEM advisors interviewed for this research were not sourced from this list. The organisations for which they worked were selected from advertisements in professional mathematics teachers' journals. After investigation of the organisations' websites, four were approached due to their familiarity with NSW schools and the nature of the services offered and all accepted. These services are

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[36] https://www.teach.nsw.edu.au/becomeateacher/teacher-education-courses

[37] https://starportal.edu.au/find-activity/1/

[38] Email from the STARPortal team March 13, 2019

specific to the secondary school environment and mathematics education in STEM, and the advisors selected are inclusive of small, private concerns solely concerned with mathematics education, as well as larger organisations offering STEM advice for mathematics as part of a suite of school services.

The final stakeholder group to be interviewed was head teachers of mathematics. There are approximately 792 government and non-government secondary schools in NSW (CESE, 2019). Given that mathematics is compulsory for all secondary students up to year 10, there is an equal potential population for this stakeholder group. Rather than attempt to recruit participants by contacting each school individually, an 'opt-in' approach similar to that of the web survey was adopted, relying once again on the relative homogeneity of this stakeholder group. Accordingly, a post on the MANSW Facebook™ page was published at the same time as the invitation to participate in the survey, and again with the reminder, asking for head teachers of mathematics willing to be interviewed for the research to contact the researcher. The five head teachers who responded were interviewed, representing both the private and public sectors and including one from a regional school.

3.2.4.3. The interview process.

Interviews were conducted either face-to-face or by telephone, as suited the convenience of the participant. For head teachers of mathematics, interviews did not take place until the late in the final school term.

3.2.4.4. The approach to data analysis.

A total of 16 interviews were conducted – 3 from the regulatory environment, 4 tertiary educators, 4 external STEM advisers and 5 Head Teachers. Each interview lasted approximately 40 minutes and all were recorded using a digital audio recorder and transcribed, in part by the researcher and in part by a commercial transcription service. The latter were checked against the audio file to ensure accuracy of transcriptions. This resulted in over 1300 pages of transcription which were loaded into NVivo™ for coding. Thematic coding proceeded on the basis of highlighting the themes identified in Table 1 whilst allowing for subthemes to emerge and inform a subsequent level of coding.

3.3. Concluding remarks

This research sought to investigate understandings and experiences of STEM education in the mathematics classroom that developed pursuant to the NSW STEM strategy and whether sustainable classroom change may have been initiated. The focus was on the landscape of STEM education for mathematics in NSW secondary schools, rather than specific implementation events. Accordingly, four stakeholder groups considered instrumental in implementing STEM education for mathematics were selected to provide a broad range of perspectives in responding to the Research Questions. The different nature of each of the four stakeholder groups demanded that different approaches be taken to data collection, and so the research design was structured on a mixed method model to facilitate the collection of both qualitative and quantitative data. This was done by way of semi-structured interview, web survey and the analysis of contextual documents. Themes emerging from the literature review in Chapter 2 were refined into four dimensions of enquiry relevant to the Research Questions and used to guide the rationale and structure of data collection and analysis.

The flexibility afforded by the mixed method approach resulted in a rich trove of data, capturing the plurality of understandings and perspectives represented by the stakeholder groups. Grounded analysis of the integrated quantitative and qualitative data yielded the findings presented in the next chapter. Many of these findings support existing research in this field, whilst, at the same time, interesting and discordant features were revealed suggesting emerging themes concerning this phenomenon. Chapter 4 presents these findings, which are then discussed in response to the Research Questions in Chapter 5.

Chapter 4. Mathematics in the age of STEM: findings from the data.

From the literature review in Chapter 2, four major stakeholder groups emerged as the focus for data collection, viz. representatives from the policy and regulatory environment in NSW, classroom mathematics teachers and those with leadership positions in school mathematics faculties in NSW secondary schools, tertiary educators of pre-service mathematics educators and external advisors and providers of STEM programs to NSW secondary schools. The previous chapter presented the research methodology, providing the rationale behind the mixed methods approach and describing the sources for, instruments used, and process employed in data collection and analysis for each stakeholder group. Semi-structured interviews were conducted with selected officers from the regulatory and policy environment, mathematics teachers in leadership positions, external STEM advisors and tertiary educators. Data were collected from the classroom mathematics teachers using a web survey (“survey”), relevant documents from the policy and regulatory environment and external providers of secondary STEM programs for mathematics retrieved from the STARportal[39] website were analysed.

This chapter presents findings from the data, structured according to the areas of importance identified in the literature relevant to this research (Table 1). The four corresponding sections are: ‘What is STEM education for mathematics?’; ‘What does STEM education for mathematics look like in the classroom?’; ‘What are the affordances and challenges of STEM education for mathematics’, and ‘What are the indicators of change that would signify the sustainability of STEM education for mathematics’. In each section, sub-headings represent themes suggested from the relevant data. Some of these themes confirm previous research, whilst others emerge from the data. As the nature of the data considered ranges across survey responses and interview analysis representing the various stakeholder groups consulted in addition to document analysis, so do the findings range from ‘direct statements’ from

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[39] https://starportal.edu.au/

quantitative data through to more nuanced expressions of a qualitative nature. Together, they form a spectrum of equal probity, offering insights from the policy and regulatory environment, mathematics teachers, tertiary educators of pre-service mathematics teachers and external providers of STEM programs into the overall nature of STEM education for mathematics in NSW secondary schools.

By way of background, in NSW school education falls under the ambit of the NSW Department of Education [DoE] and its regulatory authority the NSW Education Standards Authority [NESA]. The Australian Curriculum, Assessment and Reporting Authority [ACARA], a federal agency, has ultimate responsibility for the content of the Australian Curriculum, and all schools in NSW follow this curriculum, which is incorporated into the K-10 curriculum documents and administered by NESA. Whilst the Australian Curriculum is the core document, it is important to note that the education authorities in each state and territory may include additional material in their curriculum documents, as is the case in NSW. Additionally, NESA provides learning materials, professional development and resources for teachers within NSW. Whereas the Australian Curriculum is organised using year levels, NSW uses stages, with each stage corresponding to two years of the applicable Australian Curriculum level. For example, stage 4 in NSW corresponds to years 7 and 8 in the Australian Curriculum and stage 5 corresponds to years 9 and 10. Together, these comprise the compulsory years of secondary mathematics education. The stage 4 Mathematics curriculum is studied by all students. In early stage 5 (year 9) the curriculum branches into three progressively more difficult pathways (5.1, 5.2 and 5.3) to cater for differing student ability levels. Completion of at least the 5.2 pathway is recommended by NESA and assumed for the senior school calculus-based courses.

The Australian *National STEM School Education Strategy 2016-2026* (NSSES) (Education Council, 2015) was released in late 2015. Under the NSSES, states and territories were allocated responsibilities (and funding) aligned to achieving the overall goals of this strategy. NSW did not produce a ‘stand-alone’ school STEM strategy document. Instead, the NSW strategy was communicated to educators via dedicated

STEM webpages,[40] providing resources in the form of exemplar units of work and a broad framework of advice for planning and developing an integrated STEM unit of work.

To preserve anonymity, data sources are referred to by prefixes corresponding to the particular stakeholder group or data sources, followed by a number indicating the order in which the data were received. The prefixes used are: REG for an officer from the policy and regulatory environment; HT for a mathematics teacher in a leadership position within a mathematics faculty; TE for a tertiary educator of pre-service mathematics teachers; ESA for an external STEM advisors for secondary mathematics; R for a respondent to the survey and S for a school involved in the DoE STEM Showcase. Lastly, for the sake of brevity, the policy and regulatory environment is referred to collectively as the regulatory environment, tertiary educators of pre-service mathematics teachers are referred to simply as tertiary educators, external STEM advisors and external providers of STEM programs for secondary mathematics are referred to as external advisors and external providers respectively and mathematics teachers in a leadership position within a school mathematics faculty are referred to as head teachers.

4.1. What is STEM education for mathematics?

As noted in the literature review in Chapter 2, there is little consensus amongst researchers of a conceptual or operational framework for STEM education, beyond a broad characterisation necessarily involving some degree of integrated or interdisciplinary content learning. The focus of this research was the perceptions of the various stakeholder groups, that is, what each group understood as a working definition of STEM education for mathematics within the particular context of their group. It appears that there is a divergence between the understanding of the policy and regulatory environment and that of mathematics teachers. The former adheres largely to the research informed approach referred to in the literature, whereas the

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[40] NSW DoE STEM-NSW website (now defunct) and a series of webpages hosted on the NESA website.

latter embrace an understanding situated within the mathematics classroom and using examples from STEM subjects.

4.1.1. STEM is an interdisciplinary or integrated approach across Science, Technology, Engineering and Mathematics

This perception is supported by webpages from the NSW DoE and its regulatory authority, the NESA. Table 9 summarises the definitions and descriptions of STEM education used by the regulatory environment on these pages. These are referenced and elaborated below.

Table 9. *What the NSW Department of Education and the NSW Education Standards Authority said about STEM Education 2017 to 2021*

NSW Department of Education (NSW DoE)
2016: STEM-NSW (standalone website, now defunct) “the learning of science, technology, engineering and mathematics in an interdisciplinary or integrated approach… may include integration, inquiry and project-based learning” “alternative method of delivery of part of the curriculum, not compromising, or adding to, existing curriculum”
2016: STEM Showcase (flyer for a DoE event) “interdisciplinary approach to teaching Science, Technology, Engineering and Mathematics”
2017-2019: STEM (pages on main DoE website) “STEM…may include integration, inquiry and project-based learning”
2020: About STEM (replaces above pages on main DoE website) “an approach to teaching science and technology, and mathematics”[41], Stages 4 and 5 pages refer exclusively to “integrated STEM”; provides an “integrated STEM framework” to assist teachers planning STEM programs in secondary schools; STEM programs are planned, developed and implemented by and integrated “STEM team” “alternative method of delivery of part of the curriculum, not compromising, or adding to, existing curriculum”
New South Wales Education Standards Authority (NESA)
2017- 2021 STEM support (pages on NESA website) Supports the “integration of STEM learning in schools” by providing “programming integrated STEM” advice to teachers; provides examples of integrated models. “The emphasis of STEM is the active involvement of students in the development and production of quality design projects. Design projects consist of a design solution and a design and production folio”

As can be seen, in its original pronouncement on the stand-alone *STEM-NSW*[42] website hosted by the NSW DoE, STEM education was defined as “the learning of science, technology, engineering and mathematics in an interdisciplinary or integrated approach,”(NSW DoE, 2016d para. 1). Rather than describing alternate approaches,

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[41] https://education.nsw.gov.au/teaching-and-learning/curriculum/key-learning-areas/stem/about-stem

[42] https://web.archive.org/web/20190329154328/http:/stem-nsw.com.au/

integrated and interdisciplinary were used interchangeably, as the definition of STEM education was expanded to allow that STEM education "may include integration, inquiry and project-based learning" (para. 1). Importantly, the NSW DoE stipulates that STEM programs must deliver curriculum outcomes, "without compromising, or adding to, existing curriculum" (NSW DoE, 2016b). Additionally, the NSW DoE-hosted Secondary Schools STEM Showcase event described the stage 4 Integrated STEM Projects as showcasing "interdisciplinary approaches to Science, Technology, Engineering and Mathematics" (NSW DoE, 2016c).

Since 2020, information previously found on the *STEM-NSW* website has been partially migrated to the *About STEM* page on the NSW DoE website (NSW DoE, 2020a). Although the *About STEM* page gives no definition beyond "an approach to teaching science and technology, and mathematics" (NSW DoE, 2020a), the Stages 4 to 5 pages refer exclusively to integrated STEM programs and provide an integrated STEM framework to assist teachers planning STEM programs in secondary schools. The stipulation remains that STEM programs must deliver nothing more and nothing less than curriculum outcomes (NSW DoE, 2020b). Furthermore, STEM programs are prescribed as being planned, developed and implemented by and integrated STEM team (NSW DoE, 2020b).

NESA takes a similar approach on its STEM support webpages, providing programming advice to teachers to develop units of work and activities allowing students "to integrate their knowledge from the four STEM disciplines" (NESA, 2017c para. 3). NESA places an emphasis on collaboration by a STEM team in developing STEM units of work. To exemplify these objectives, NESA has developed and published six STEM units of work (three stage 4 and three stage 5) ("STEM units") and two STEM Pathway programs for stage 5 mathematics ("STEM Pathway programs"). Each of the STEM units of work involves integrating outcomes across the three distinct NSW STEM curriculums – Science, Technology Mandatory and Mathematics - together with envisaging a collaborative effort across these subject areas. In contrast, the two STEM Pathway programs represent a departure from a collaborative, interdisciplinary model and are considered in Section 4.1.2. NESA goes on to emphasise that STEM actively involves students in a design project (NESA, 2017c). This apparent characterisation of

STEM as necessarily involving design (typically associated with projects in the Technology curriculum) is discussed in Section 4.2.1.

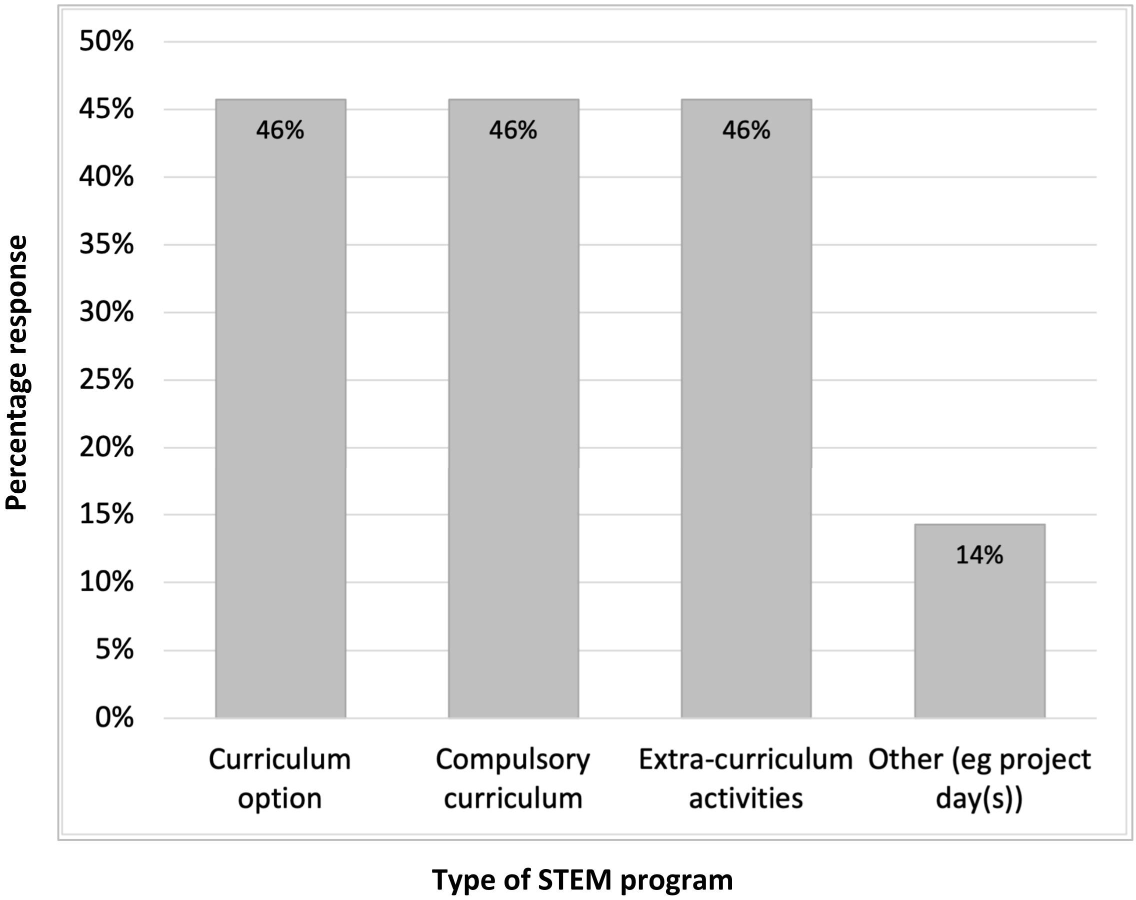
4.1.2. Mathematics teachers see STEM education as situated within mathematics

The model of STEM education promoted by the regulatory authorities was not universally understood by its audience of educators. Both tertiary and secondary educators noted the confusion surrounding the definition offered, as STEM seemed to be “understood differently by different people” (TE1 and HT3). In particular, teachers were uncertain of what was being asked of them in implementing the STEM education model in the classroom.

> I have heard of STEM but not sure how it’s meant to be implemented. (R66)
>
> I don't know what it looks like, I don't understand it. (R14)
>
> …to be honest with you, for a long time, I didn’t know what it meant ... I was confused. I think, when I looked at other people, I kind of got the sense that, it was different things, for different people (HT3)

Optional curricula or extra-curricular STEM activities, such as coding and robotics, together with STEM project day(s), were considered by mathematics teachers as constituting a STEM education program in their school (Figure 2).

Figure 2. *Nature of Student Participation in STEM programs in your School. (n = 35)*[43]



Head teachers of mathematics also nominated extra-curricular robotics and coding activities as STEM programs within their schools (HT1, HT2 and HT5). Another described adapting external resources for use in the mathematics classroom (HT4) and some admitted to giving up in the face of the complexity of the task ahead:

> I have to say, we don't have a STEM co-ordinator anymore…because I think the one we had, just gave up. (HT3)
>
> …the (STEM) Committee met a few times to try and incorporate some sort of stage 5 option or some sort of stage 5 STEM course…Its very difficult to do it. Eventually the STEM Committee was disbanded. (HT1)

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[43] Question 9 of the Web Survey. Respondents to this question could choose more than one answer. Hence the percentages do not sum to 100.

However, even where STEM programs were in-curricular, they were not necessarily open to all students.

> (The) majority of student body is left out, because it is perceived that low ability students will not be pursuing a stem (sic) career...students are hand-picked to make the school look good. (R16)

Similarly, in 13 of the 27 DoE STEM Project ("STEM Project") programs[44], student participation in the Projects was on the basis of ability,[45] a feature also noted by ESA1[46].

> I was surprised by how many schools just ran it with the gifted and talented stream or something like that. (ESA1)

Perhaps in response to this lack of clarity and direction, a perception of STEM being situated within mathematics emerged from the survey. The preferred response selected by mathematics teachers in the survey supported a personal understanding of STEM education for secondary mathematics as using examples from the other STEM subjects to make connections with the students' learning in mathematics (Figure 3). This response was chosen from descriptions ranging from optional, extra-curricular STEM activities through to a fully integrated and interdisciplinary in-curricula STEM education model.

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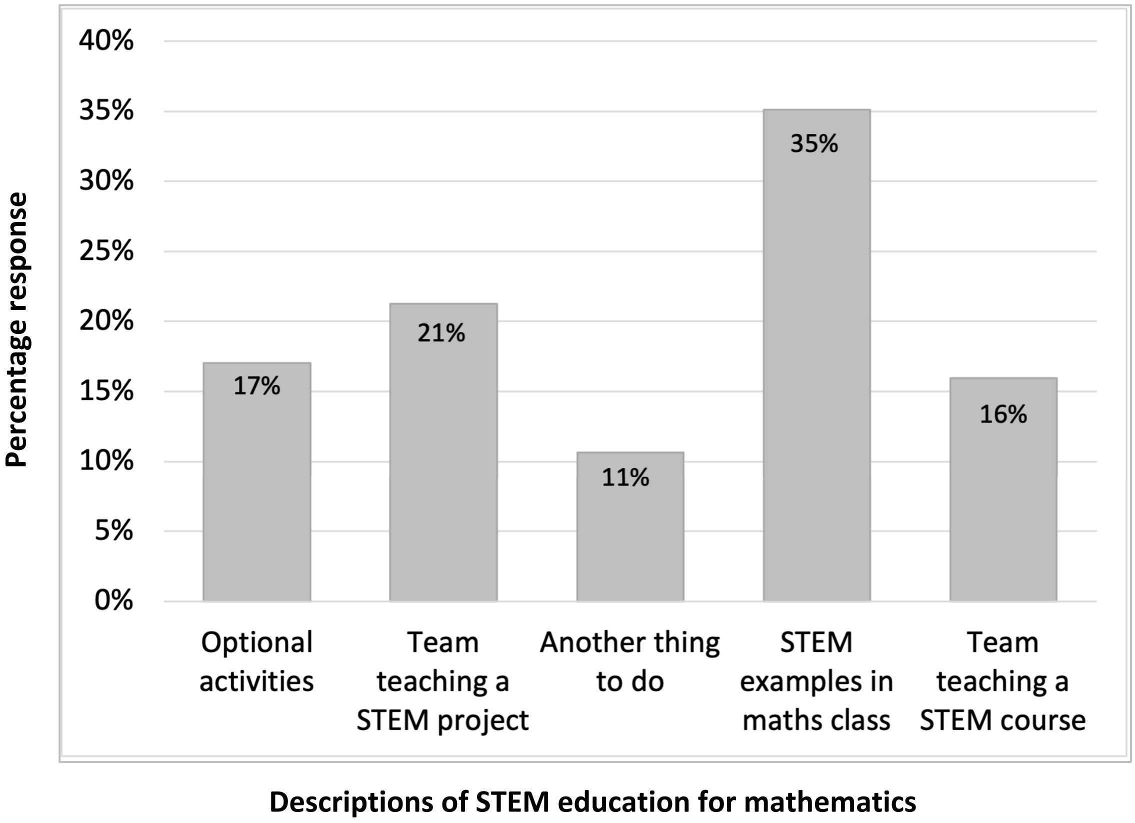
[44] https://web.archive.org/web/20160928053037/http://www.stem-nsw.com.au/teaching-stem/stage-4-stem-projects

[45] See Appendix F STEM Showcase Project duration and student participation.

[46] The organisation in which ESA1 worked provided funding to approximately 60 schools over three years to introduce an integrated STEM project.

Figure 3. *What does STEM education look like to Secondary Mathematics Teachers? (n = 61)*[47]



Unpacking this response suggests two ideas, both of which contrast with the model of STEM education promoted by the regulators and policy environment. Firstly, the survey response recalibrates notions of STEM education away from a supposed equal sum of parts (the component STEM disciplines) to focus on the importance of mathematics education, discounting, if not disregarding, the other component disciplines. Although it might be expected that teachers would privilege their own discipline, this position may nevertheless be a reaction to a common perception described in the literature that STEM education

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[47] Question 6 of the Web Survey. Respondents to this question could choose more than one answer. Hence the percentages do not sum to 100.

programs neglect or downgrade mathematics, as voiced by survey respondents R38 and R46.

> (STEM is) Team teaching in a standalone course where the emphasis is placed on STE and little M is covered. This is not what it is meant to be but rather what it seems to be. (R38)
>
> I … worry that some rigor has been sacrificed in order to develop fashionable programs such as STEM. (R46)

This sentiment was expressed beyond the survey and echoed by a head teacher with experience in STEM programs and a tertiary educator of pre-service mathematics teachers.

> …well it should mean, I suppose, is that maths is incorporated as part of a bigger picture across the curriculum. But the reality, I think, for STEM within school is that maths seems to be an add on rather than a major part of STEM. (HT4)
>
> While the integration they've used is good, I think the danger is that the actual intrinsic value in mathematics, can sometimes be lost. (TE3)

Secondly, the response situates STEM education for mathematics within the mathematics classroom, physically and pedagogically, preserving mathematics as a distinct branch of knowledge. Hence STEM education for mathematics is reframed, away from an unconditionally collaborative effort amongst educators. Although some degree of collaboration might be necessary to source disciplinary valid examples for use, such examples would be seen through the lens of mathematics.

The perception of STEM education as situated within the mathematics classroom is also supported by the STEM Pathway programs (NESA, 2017a; NESA, 2017b), presented as alternatives to the standard stage 5 mathematics programs. Both comprise a series of units of work to be either followed in full or used as stand-alone resources to be incorporated from time to time into traditional programs. Teaching and learning activities compact and combine curriculum content across strands to focus on developing connections between student learning in mathematics and real-world applications. Whilst cross-discipline opportunities are identified (extending beyond science and technology), the programs may be fulfilled entirely within the mathematics classroom and satisfy the majority of the curriculum outcomes necessary for students to advance to a stage 6 (senior) mathematics course. They are *not* designed to fulfill curriculum objectives outside of mathematics. The STEM Pathway programs are not characterised by any form of integrated or interdisciplinary learning, nor do they necessarily involve collaboration. Furthermore, this recognition of STEM education as achievable solely within the mathematics classroom is validated from interview comments from the policy and regulatory environment:

> …if we're working just in the mathematics classroom, again, the key characteristic is students having the opportunity to connect to the learning that they're doing in that classroom to areas outside, and to look at the applications of the mathematics components of the course and how they apply to real life and practical applications beyond the classroom… (REG2)

4.2. What does STEM education for mathematics look like in the classroom?

The previous section highlighted perceptions of STEM education for mathematics. This section turns to actualised STEM education programs and the role of mathematics in such programs, referencing data from the 27 DoE STEM Project programs[48], the stage 4 STEM units (NESA, 2017c), the survey and interview participants. NSW secondary school students in stage 4 are required to study 8 subjects[49], each with mandated hours of study over the two stage years, leaving little spare time in the school timetable for additional learning experiences. Implementing a STEM program integrated across two or more of the STEM curriculums and embedded in the school timetable over a period of time (as distinct from an activity day or days or

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[48] Available for download at https://web.archive.org/web/20160928053037/http://www.stem-nsw.com.au/teaching-stem/stage-4-stem-projects

[49] English, Mathematics, Science, a language, a Creative Arts subject, Human Society and its Environment (comprising History and Geography), Personal Development, Health and Physical Education and Technology Mandatory.

an incursion) demands, at the most basic level, contribution of class time and content from participating subject areas. At the same time, these subject areas must continue to adhere to overall curriculum programming and assessment requirements, which may or not be achieved within the STEM program. Choices made in class-time contribution and content inclusion determine the implementation structure of the STEM program, which, together with the program's overall outcome, influence the program's character and how it is positioned and perceived within the school's curriculum. Analysis of the STEM Project programs, the survey and the STEM units draws attention to these choices, either made (in the case of the STEM Project programs and the survey) or anticipated (in the case of the STEM units). Such choices suggest that Technology Mandatory ("Technology") has been used to provide the most coherent vehicle for implementing a STEM program within schools. Additionally, examining the mathematics learning involved by way of curriculum outcomes included, it appears that student experience of mathematics in STEM programs is often limited to process-driven content and skills required for the design and/or production of a physical artefact, lacking the introduction or development of higher order mathematical knowledge.

4.2.1. Technology as the curriculum host for STEM programs in NSW schools

The preferred collaboration model for the STEM Projects was the involvement of teachers from all three of the Technology, Mathematics and Science subject areas (20/27 STEM Projects, or 74%[50]). This is also the sole collaboration model presented in the STEM units. However, in the case of the STEM Projects, this did not equate to an equal distribution of class-time across the subject areas, with Technology being the greatest contributor. Table 10 presents this information from these STEM Project schools. In two-thirds of these schools, over 50% of the STEM Project class-time was spent in Technology. Allocation of additional class-time outside timetabled subject classes was rare (2 schools only), and the STEM Project was in the main delivered by

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[50] See Appendix G STEM Showcase Project subject area involvement.

subject teachers during normal timetabled subject classes. Some or all of participating teachers from Technology, Science and Mathematics might be involved in delivery, regardless of the subject classes. The STEM units do not give any information about recommended class-time contribution, however in all three units Technology was involved throughout the entire program duration of 8 to 9 weeks, whereas in two of the three units, mathematics was involved for weeks 1 to 4 only. An 8 to 9-week time period represents the majority of a school term[51], and indeed this appears to be the favoured duration for a STEM program, with 65% of the STEM Projects lasting this long[52] and 71% of survey respondents reporting programs of 5 weeks or more[53].

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[51] In NSW the school terms are typically 9 to 11 weeks in duration
[52] See Appendix F STEM Showcase Project duration and student participation
[53] Question 17 of the Web Survey (n = 14).

Table 10. *STEM Showcase Project programs involving Technology, Mathematics and Science programs involvement by subject area*

School	Technology	Mathematics	Science	Dedicated STEM lessons	Usual subject lessons	Notes on delivery of STEM Project
S1	33.3%	33.3%	33.3%	✓	✓	Additional 3-hour STEM block per fortnight
S2	50%	15%	35%		✓	Subject teachers taught STEM independently
S3	50%	15%	35%	✓		Technology dedicated as STEM lessons; all three subject teachers in each class
S4	50%	25%	25%	✓	✓	Additional 3-hour STEM block per week
S6	52%	24%	24%	✓		Taught in Technology periods with extra classes from Mathematics and Science
S8	30%	40%	30%		✓	
S9	33.3%	33.3%	33.3%	✓		Delivered in a dedicated STEM room
S10	62%	19%	19%		✓	Subject classes timetabled on same days for teacher and class flexibility
S13	51%	16%	33%	✓	✓	Technology dedicated as STEM lessons with additional classes from Mathematics and Science
S14	50%	25%	25%		✓	
S18	50%	25%	25%		✓	Term 1 delivered by Mathematics and Science teachers; Term 2 entirely in Technology.
S20	33.3%	33.3%	33.3%		✓	
S21	38%	4%	58%		✓	
S22	46%	8%	46%	✓	✓	Additional two dedicated STEM classes per cycle taught by Technology
S23	50%	25%	25%	✓		Taught in dedicated STEM learning space by Technology teacher and either a Mathematics or Science teacher.
S24	100%	0%	0%	✓		Taught in dedicated STEM learning space by Technology teacher and either a Mathematics or Science teacher.
S25	50%	25%	25%	✓		Taught by Technology teacher within a dedicated STEM learning space with collaboration from Agriculture, Mathematics and Science
S27	100%	0%	0%	✓		Taught entirely in Technology lessons with a Mathematics or Science teacher joining for one lesson per cycle

Furthermore, in all but one of the STEM Projects, the overall outcome was the design and/or creation or construction of an artefact and all were assessed by the submission of a design folio (physical or electronic), often accompanied by a presentation of elements of that folio[54]. This is consistent with the model presented in all of the STEM units[55]. The Technology curriculum at the time[56] required students to complete at least four design projects over the course of stage 4 and present design folios for assessment (Board of Studies NSW, 2003, p. 14)[57]. In this way, the STEM projects and STEM units serve to fulfil Technology curriculum outcomes[58] and assessment requirements for one of these mandated projects. In contrast, details of assessment for the mathematics content described in the STEM Project programs were scant or missing. In four programs only a common assessment rubric for the folio included specific mathematics outcomes. Some programs noted partial inclusion of mathematics outcomes in the folio or presentation (without nominating the specific outcomes), whilst others were silent or conducted assessments separate to the STEM Project. Survey respondents confirmed that, in 50% of the STEM programs in which they had been involved, separate mathematics classes were held, and relevant stage curriculum outcomes were not met during the program[59], with 62% reporting that mathematics outcomes were assessed outside STEM programs[60]. On the other hand, the STEM units, as might be expected given their provenance, detail assessment strategies for each of the component subjects by stage curriculum outcome[61]. Nevertheless, a folio still features as the overall assessment instrument, but specifies inclusion of components for mathematics assessment, for example diagrams or sketches marked up with calculations and formulas. The characterisation of a STEM

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[54] See Appendix H STEM Showcase Project description and assessment

[55] See Appendix I NESA STEM Units description and mathematics syllabus assessment

[56] The Technology curriculum applicable to the STEM Projects (Board of Studies NSW, 2003) was superseded by the NSW Curriculum for the Australian Curriculum Technology Mandatory Years 7-8 Curriculum (Technology 2017 curriculum) (NESA, 2017d)

[57] This assessment requirement remains unaltered in the Technology 2017 curriculum (p. 20)

[58] See outcome 4.1.1 of the Technology curriculum (Board of Studies NSW, 2003) together with outcomes TE4-1DP and TE4-2DP of the Technology 2017 curriculum (p. 14).

[59] Questions 13 and 14 of the Web Survey (n = 11 for both questions).

[60] Question 19 of the Web Survey (n = 14).

[61] See Appendix I

unit of work as a design project leading to a design and production folio is further supported by NESA in its advice to teachers in developing a STEM unit of work. By using language common to the Technology curriculum, such as “STEM is … the development and production of quality design projects” and “Design projects consist of a design solution and a design and production folio” (NESA, 2017c para. 5), Technology is positioned as the logical host for the implementation of a STEM project. This positioning in the implementation is recognised by regulators and tertiary educators as such.

> STEM in the way in which most teachers interpret it really is grounded very much within the technology and the science space, and in a design of a product.” (REG3)
>
> But then if you look at how it seems to be being enacted in schools, it’s very much they’re trying to do that integrated STEM, whether they have an integrated STEM days, it’s, it’s often far more aligned with design and technology than it is with science and maths. (TE1)

With an increased focus in schools of STEM as project-based, ESA1 observed a movement from Technology and Science as equal drivers of the programs to Technology becoming the dominant partner. In no STEM program was Mathematics the driver.

Where the production or construction of an artefact is required, it is obvious that the resources and workspace afforded by Technology are essential. However, positioning Technology as providing the overall vehicle for implementation, satisfying Technology curriculum outcome areas, situates the STEM Project in that physical *and* curriculum space. Rather than being integrated across subject areas, the dominant model in the STEM Projects and the STEM units appears to integrate other subject areas into Technology. As can be seen from Table 10, some schools designated usual timetabled Technology lessons as ‘STEM lessons’. The implications of positioning Technology as the vehicle for implementing STEM programs within the NSW curriculum structure are considered in Chapter 5.

4.2.2. *Mathematics in learning in STEM programs privileges process-driven outcomes*

In NSW the Mathematics curriculum is organised into four strands, namely working mathematically, number and algebra, measurement and geometry and statistics and probability (Board of Studies NSW, 2012a, p. 35). This consideration of mathematics curriculum outcomes included in STEM programs excludes the outcomes from working mathematically, since the collective ambit of the three working mathematically outcomes (communicating, problem solving and reasoning) are skills universally applicable to project work. The development of working mathematically skills does not attach to specific content outcomes and rather is embedded in the manner in which learning activities are designed across all content outcomes. Indeed, these outcomes were recorded in various combinations in all STEM programs investigated, with 21 from the 27 Project programs (78%) recording all three. The focus instead is on outcomes in the remaining three strands. These outcomes from the NSW Mathematics curriculum are listed in Appendix M.

As a broad indicator, survey responses nominated number, measurement and statistics as the areas of strand content most commonly utilised in stage 4 and 5 STEM programs in which respondents had been involved (Figure 4). This breakdown is consistent with the outcomes recorded in the STEM Project and the STEM unit programs (Figures 5 and 6 respectively).

Figure 4. *Mathematics Content in STEM programs by Curriculum Strand from Web Survey (n = 14)*[62]

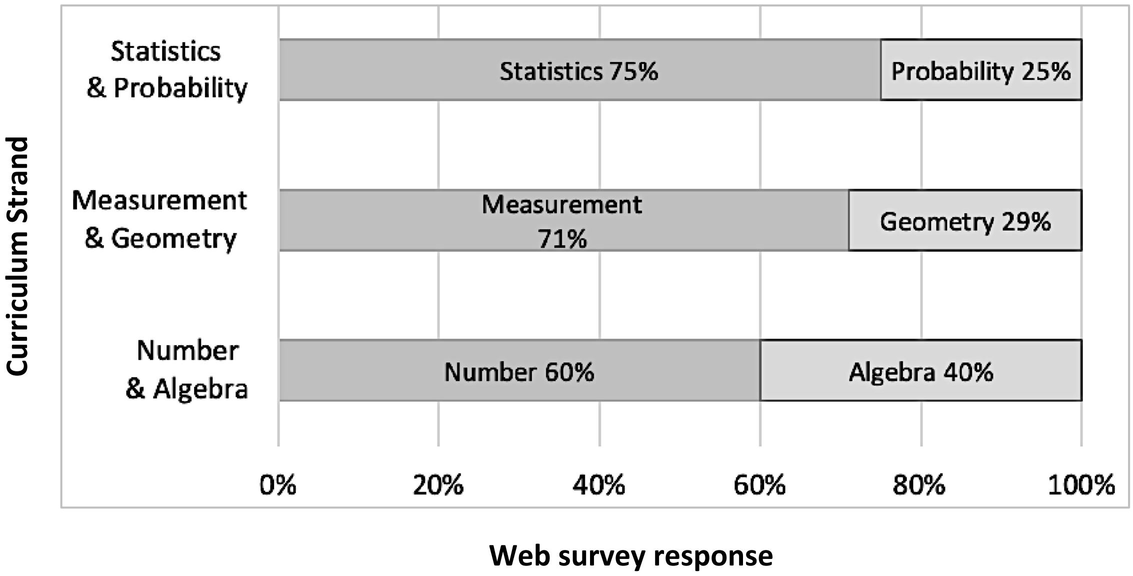
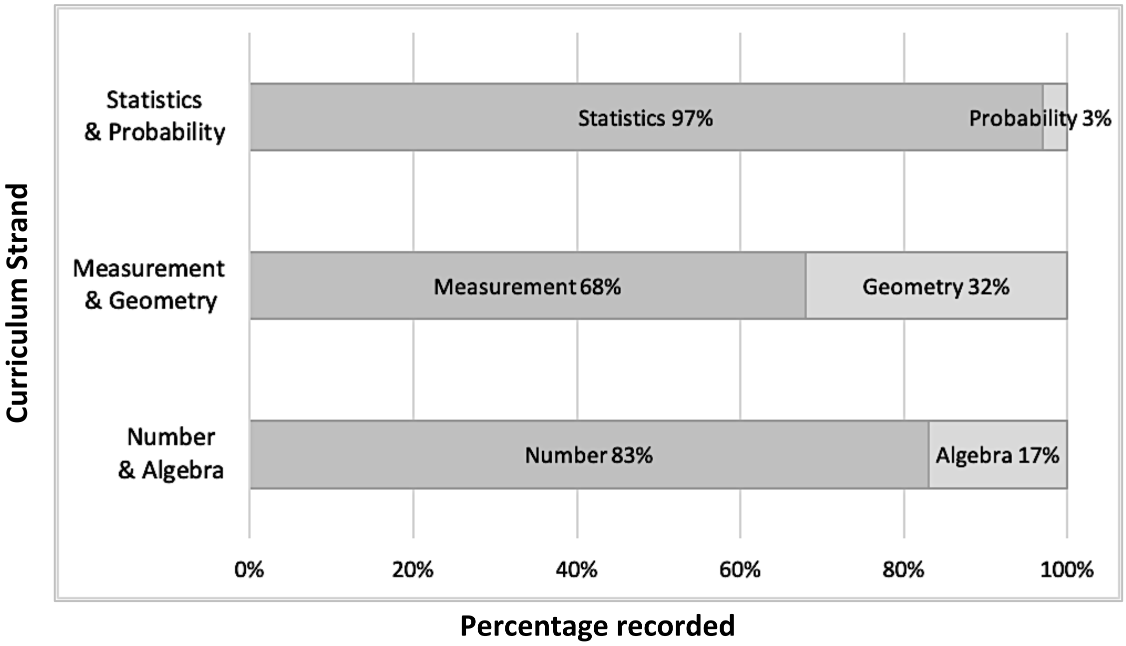


Figure 5. *Mathematics Content in DoE STEM Project Programs by Curriculum Strand*[63].



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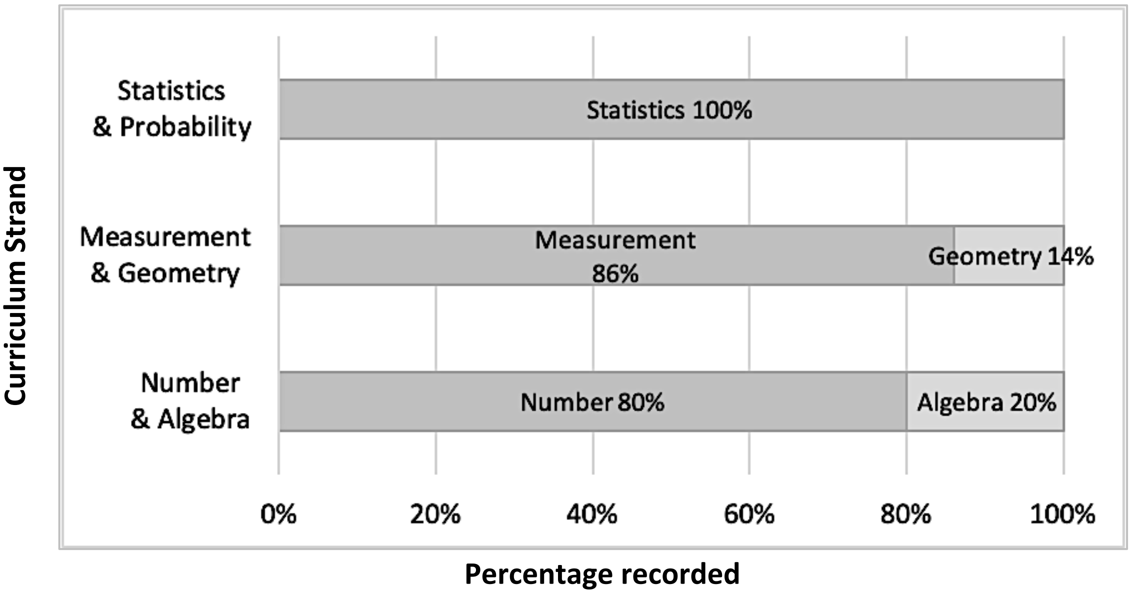
[62] Question 15 of the Web Survey. Working Mathematically has been excluded as an outcome.

[63] See Appendix J Mathematics outcomes recorded in the 27 DoE STEM Showcase Project programs excluding Working Mathematically

Figure 6. *Mathematics Content in NESA STEM units by Curriculum Strand*[64].



The tables of individual curriculum outcomes included in each of the STEM Projects and the STEM unit programs allowed more detailed scrutiny and these outcomes are recorded in Appendices 10 and 11 respectively. In both the STEM Projects and STEM units, the outcomes from the number and algebra strand featured strongly, noticeably those involving operating with integers, fractions, decimals and percentages together with rates and ratios. This is not surprising, given that any activity that involves counting, measuring or calculating will invoke one of more of these outcomes. Given the emphasis on designing and producing an artefact (Appendix H), outcomes in this strand were routinely and collectively attributed to activities[65] involving costing the project using an Excel spreadsheet (MA4-4NA, MA4-5NA and MA4-6NA) and using ratios to scale the artefact (MA4-7NA). Examples of these activities are:

> Cost of materials and budget analysis of their project using scaffold sheet and transfer information to an excel spreadsheet for analysis. (S3)

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[64] See Appendix K Mathematics outcomes recorded in the three stage 4 NESA STEM units programs excluding Working Mathematically

[65] Activities attributed to curriculum outcomes are set out in Appendix L.

> Use rates and ratios in the design process/student scale down their toy, basing their toy on a bigger item e.g. car, plane. (S8)
> Costings for each project are calculated using Excel spreadsheet. Time considerations are built in (wages). Present budget for each design. Construct graphs of percentage of different resources and identify GST components within budget. (S4)
> Using data from energy audit, students to calculate the actual power consumption of each electrical device/appliance, tabulate in the table/Excel with energy rating, energy in cents per kilowatt-hour, and total energy consumption and present to class. (S23)

Similarly, the measurement and geometry strand outcomes for perimeter, area and volume lend themselves to extensive use in the design process. For example, from S20, when considering the design for living quarters on a mission to Mars, students were required to calculate the perimeter and area of their travel pod, meeting parameters such as minimum land area, a range of shapes to be included and maximum perimeters, as well as planning how to fit everything needed for the two-and-a-half-year journey into a one cubic metre box using only a measuring tape, pencil and paper. Further examples are:

> Students design a water bottle for the GWS Giants with a volume of 750mL. Calculating Surface area of their bottle to ensure logo designs will fit. (S22)
> Define formulas for perimeter of plane shapes and circle. Use perimeter to aid the design process - size of toy, is it in proportion? Is there material available. Define formulas for area of plane shapes and circle. Use area to aid in the design process - size of toy, is it in proportion? Is there material available? (S8)

The most utilised individual outcome overall was from the statistics and probability strand, namely the collection, display and interpretation of single variable data sets (MA4-19SP). The utility of this outcome in both the initiation and the testing and evaluation phase of the design process is evident, and techniques associated with the outcome are also found in the Technology curriculum[66] and the Science curriculum[67]. A typical activity for this outcome was:

> …determine the type of data they will be collecting and how to best display this data - Practice using spreadsheets and making displays from this information on Excel. (S11)
> Sketch data logging sheets and learn to transform to excel sheets. Graphing of results using excel etc. Analysis of results and displays. Identify trends in data and relate theory to project for improved outcomes. Nature of data. Value of repetition and repeat-ability. Outliers. Analysis of graphical results of test flights. (S14)

The quantification of mathematics content in Appendices 10 and 11 highlights the inclusion of important but largely process and skills driven outcomes from each strand, rather than outcomes representing the development of higher order algebraic, analysis and reasoning skills. Notably, outcomes introducing algebraic thinking and techniques (MA4-8NA to 11NA) are rarely included, together with the outcomes leading to geometric classification and foundations of proof (MA4-16MG to 18MG). In addition, although the outcome concerning angle properties arising from transversals on parallel lines (MA4-18MG) was included in 8 Project programs, in 7 of these the description of activities attributed to this outcome did not appear to extend student application of learning beyond stage 3 measurement and naming of angles (MA3-16MG). The following activities illustrate this.

> Introduce but don't define the possibility of angle of trajectory as a factor in rocket launch / Learn to estimate, and measure angles.
> Geometry bisectors, of lines and angles etc. / Launch angles.

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[66] Outcome 4.2.2 of the Technology curriculum (Board of Studies NSW, 2003, p. 24) and implicit in the description of Design Projects in the Technology 2017 curriculum (NSW Education Standards Authority, 2017d, p. 21).

[67] Outcome WS7.1 of the Science curriculum (Board of Studies NSW, 2012a, p. 36).

> Measurement. Imagining (approximating) and constructing angles. Language of angles. (S14)
>
> Apply angle properties to design and determine the angle of chassis to maximise speed and generate more power. Naming convention and measuring angles. Students practise measuring angles using a protractor by following these steps: 1. Place the protractor over the angle to be measured. 2. Move the protractor so the centre of the baseline is on top of the vertex of the angle. 3. Make sure the baseline is on top of one arm of the angle. 4. Hold the protractor carefully so it does not move. 5. Count forwards from 0° along the scale until you reach the other arm of the angle. 6. The number where this arm crosses the scale tells you the size of the angle in degrees. Students use GeoGebra to investigate angle relationships. (S12)

Reliance on stage 3 skills and favouring process over analysis is also evident in the statistics and probability strand. Although the outcome concerned with collecting, representing and interpreting data (MA4-19SP) was the most commonly used overall, statistical analysis using measures of location and range (MA4-20SP) was far less represented and the probability of simple and compound events was largely ignored. The mathematical application skills of calculating, measuring and collecting and representing data are important and indeed can and are used in any design and production process. The predominance of these outcomes may be as a result of the conceptualisation of a STEM program as necessarily resulting in the production of a physical object. However, to limit mathematical involvement in a STEM program to the application of a repetitive set of skills raises questions about the efficacy of the class-time contribution of mathematics to an integrative, collaborative STEM program in terms of curriculum progression and student experience of mathematics in STEM.

4.3. The affordances and challenges of STEM education for mathematics

Although the affordances and challenges of the student experience in STEM programs have been well researched, the teacher experience, and in particular that of mathematics teachers, has attracted less attention. This research looked specifically at the mathematics teacher experience, together with these teachers' perceptions of the student experience. Findings from the web survey, searches of the STARportal site and analysis of the Mathematics and Science curriculum documents describe a conflicting situation. Mathematics teachers welcome STEM education as offering professionally stimulating and interesting teaching opportunities and recognise that students are more interested and engaged in their learning. At the same time, significant hurdles are presented by difficulties experienced in programming mathematics content in STEM programs to an extent sufficient both to meet curriculum outcome requirements and to foster reasoning and analysing skills. There is a demand for professional development to assist with this programming together with STEM resources that make meaningful connections between the other STEM subject areas and the mathematics curriculum. However, it appears external providers of STEM programs have very little on offer for mathematics and connections between the Mathematics and Science curriculums are problematic.

4.3.1. Students enjoy learning in a STEM environment but nevertheless struggle with applying their mathematics learning

Confirming research findings, increased engagement (75%) and interest in practical applications of their mathematics learning (81%) were identified by survey respondents as major benefits to students, although it is interesting to note that only 21% believed that teaching in a STEM environment would lead to an improvement in student results in mathematics[68]. Nevertheless, significant challenges to student learning were also recognised (Figure 7), notably the high level of support required by all students and the struggles faced by lower achieving students.

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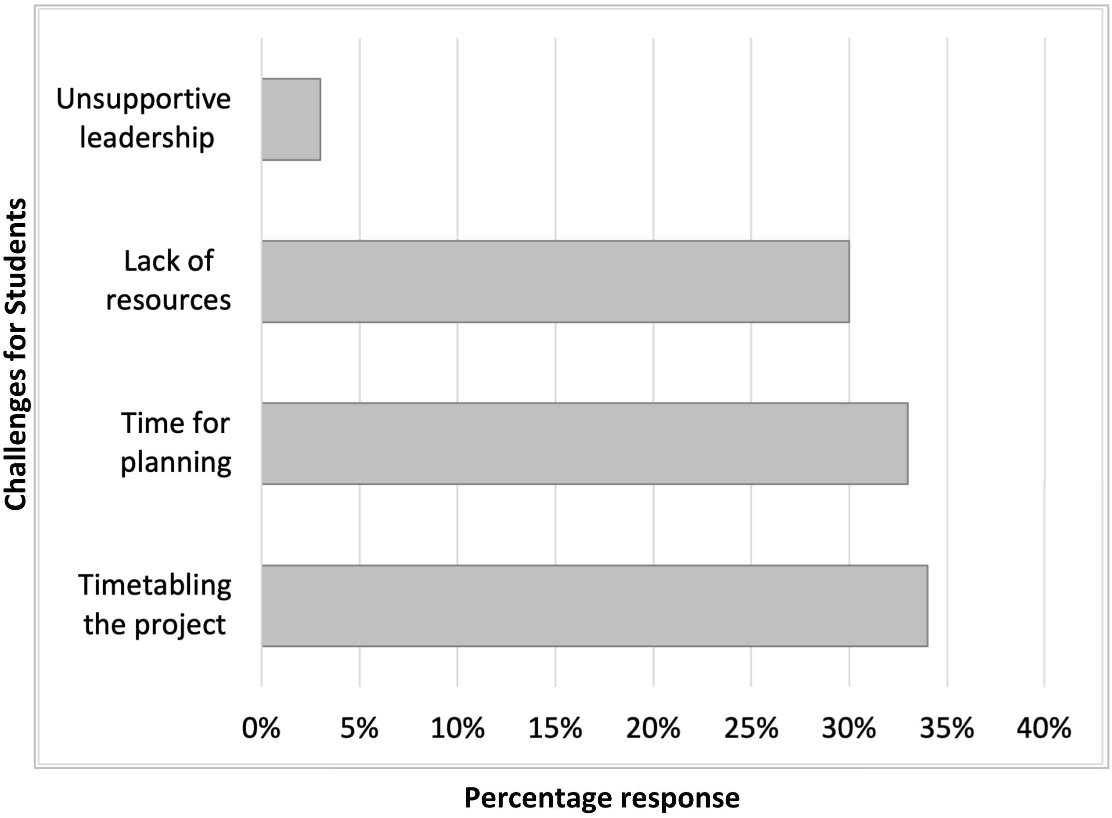
[68] Question 22 of the Web Survey (n = 48). Respondents to this question could choose more than one answer. Hence the percentages do not sum to 100.

Figure 7. *The Challenges for Students from Teaching Mathematics in a STEM environment (n = 48)*[69].



Observations from regulators, head teachers and tertiary educators clarify these challenges. They highlight the difficulties faced by all students when presented with the unfamiliar and less structured learning environment of a STEM program:

> I think that comes down to missing steps of building kids and teachers up to a point where they are ready to embark on a task of that nature, so we saw this (lack of) engagement because kids were not sure of where to start because they're not familiar with that style of learning, so there was some frustration there in activities… (REG2)

together with specific difficulties experienced by the lower ability students.

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[69] Question 24 of the Web Survey. Respondents to this question could choose more than one answer. Hence the percentages do not sum to 100.

> …but students that are not good at Maths just fall back on the when are we ever going to use that, I'm not going to do that job, therefore I don't need to learn it. (HT4)
>
> …there's this programme we planned up before we started, and even after week three we've come to realise some of the kids are way past that point, and some of the students are still colouring in and playing with stuff that isn't even relevant. And so, I think that's also an issue. How do you bring the whole cohort through without losing some of them and without also inhibiting some of the students that are more able? (TE4)

4.3.2. Teaching mathematics in a STEM environment is professionally satisfying

Mathematics teachers emphatically supported teaching mathematics in a STEM environment as a positive experience. 83% of survey respondents believed that using ideas from STEM education would improve or has improved teaching in stages 4 and 5[70]. From Figure 8, not only did teachers feel that teaching was more interesting (58%), but they also enjoyed expanding their subject content knowledge to understanding mathematics connections and use in other subject areas (54%), or, in the words of R29, it affords teachers "the opportunity to see outside their own subject area".

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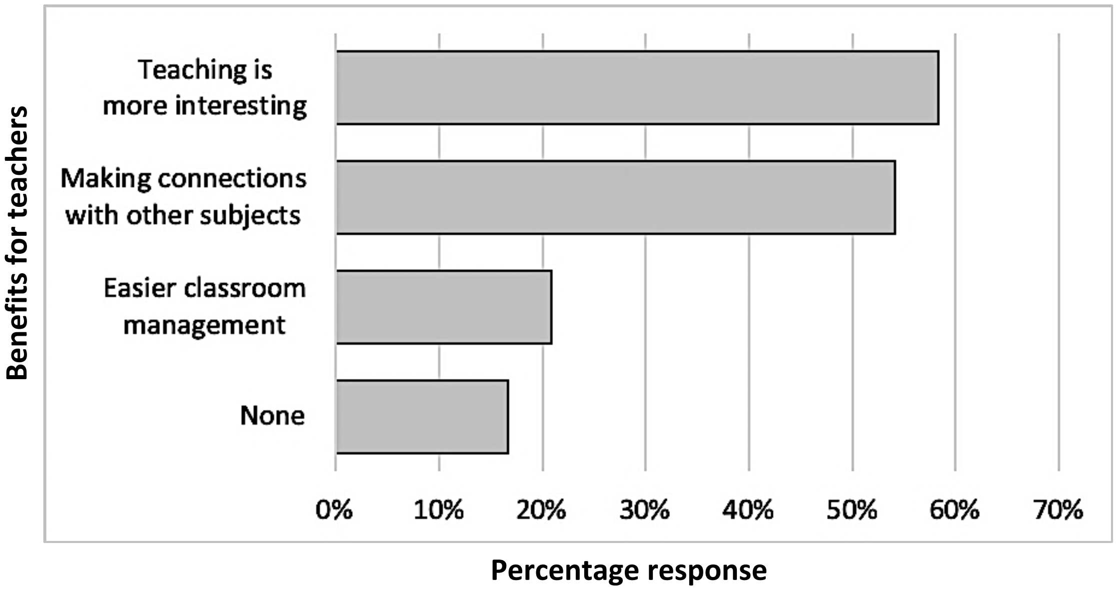
[70] Question 21 of the Web Survey (n = 48).

Figure 8. *The Benefits for Teachers from Teaching Mathematics in a STEM environment (n = 48).*[71]



This enthusiasm was echoed by head teachers of mathematics.

> I think it makes the teaching more interesting. If you're teaching something the way you've learnt it, that's for new people and for someone who's more experienced, the way they've taught it for the past 10 years, it can get a bit boring and dreary. (HT1)

4.3.3. Including meaningful mathematics content in STEM programs is difficult

Notwithstanding this positive perception, teachers identified many challenges to teaching STEM, and specifically mathematics using STEM strategies[72]. These can be grouped broadly into concerns about the mechanics of a STEM program in the whole-school environment, and concerns particular to the teaching of mathematics in a STEM environment. Figure 9 focuses on the formers whilst Figure 10 focuses on the latter.

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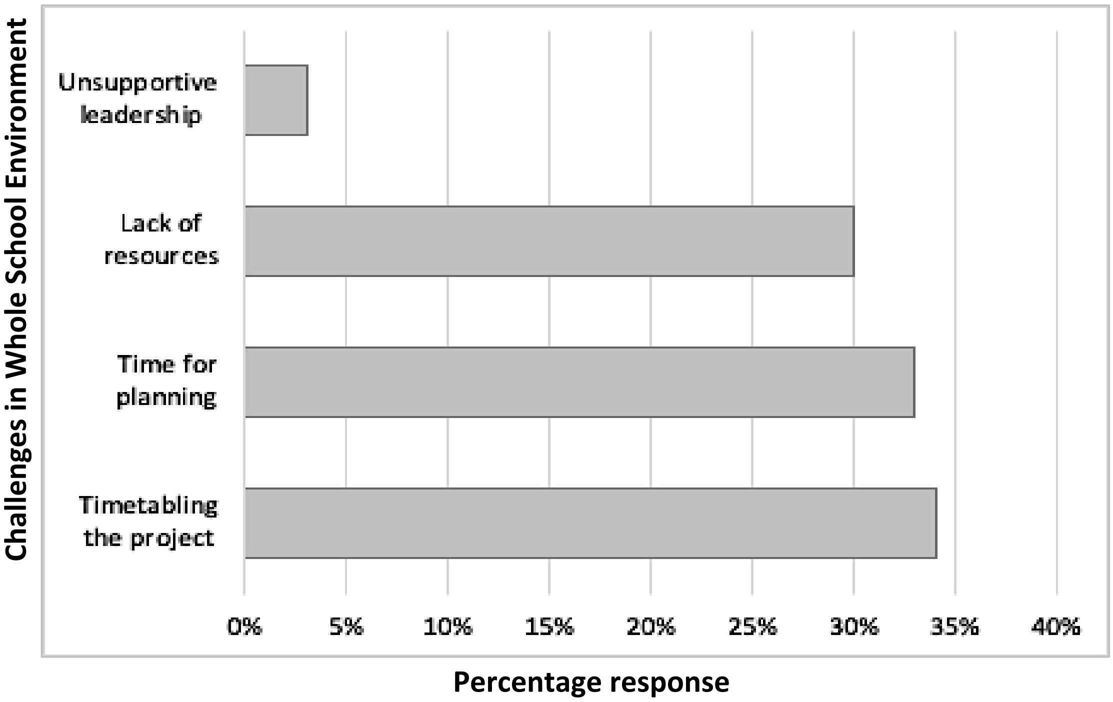
[71] Question 23 of the Web Survey (n = 48). Respondents to this question could choose more than one answer. Hence the percentages do not sum to 100.

[72] Question 25 of the Web Survey (n = 48).

Figure 9. *Challenges in the Whole-School Environment in Implementing STEM. (n = 48)*[73]



As can be seen, the three major challenges affecting the whole school concerned resourcing and timetabling the project, together with allocating sufficient time for teachers to meet across participating disciplines to plan and develop the project. The importance of allocating time for the teachers from the participating subjects to talk to each other in the same room to break down the discipline silos is noted by ESA3.[74]

> …one of the most successful things is just to make sure that once a week or once per fortnight there's a time tabled lesson for three people, one maths, one science, one TAS, to meet and plan for the next thing…(otherwise) they find it really hard to get together. (ESA3)

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[73] Question 25 of the Web Survey. Data have been disaggregated into 2 sets – one set is used to generate Figure 9 (whole school challenges) and the other to generate Figure 10 (challenges specific to teaching mathematics in STEM).

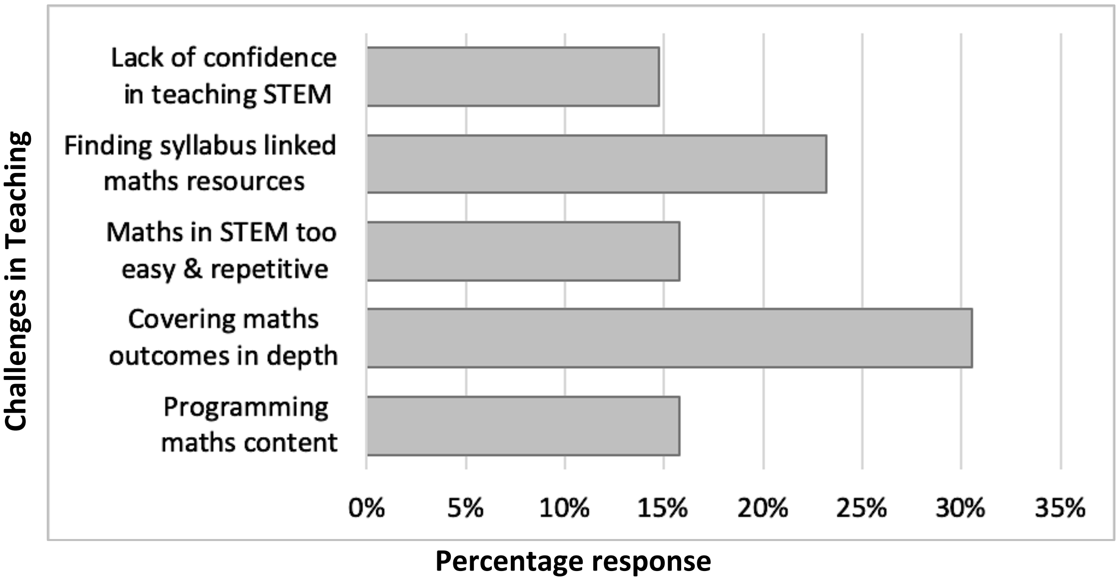
[74] ESA3 works for an organisation providing extensive training and support for schools implementing STEM programs.

The cost of resourcing a STEM program is highlighted by this response. This is even more so when the cost of time release for participating STEM teachers to meet is considered. ESA1 reported that:

> …most of the funding was allocated towards teacher professional learning and time release to actually develop projects…. (ESA1)

Finally, although the leadership in the respondent's schools was largely supportive of STEM education, it cannot be taken as a given, as confirmed by a head teacher (T2) observing that STEM education was "just something we (the mathematics faculty) are doing", rather than being driven at leadership level.

Figure 10. *Challenges in Teaching Mathematics in a STEM Environment (n = 48)*[75]



The inclusion of mathematics content in STEM programs clearly presents challenges. Commenting on this, respondents' concerns appear to be threefold. Firstly, the mathematics, even if specifically linked to curriculum outcomes, may be too trivial or insubstantial to satisfy the scope of the outcomes.

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[75] Question 25 of the Web Survey. Data have been cleaned to remove responses not directly concerned with teaching mathematics and then aggregated.

> Very low level of maths. The… STEM courses only required some basic statistic manipulation, i.e. summary statistics. (R43)

Secondly, there may be only a small amount of mathematics programmed into the STEM program.

> There was a bit of maths as applied understanding of ratio for model-making (which was useful), but otherwise it was very low on maths curriculum content. (R65)

Thirdly, the design and production nature of STEM programs does not lend itself to the development of theoretical skills in mathematics.

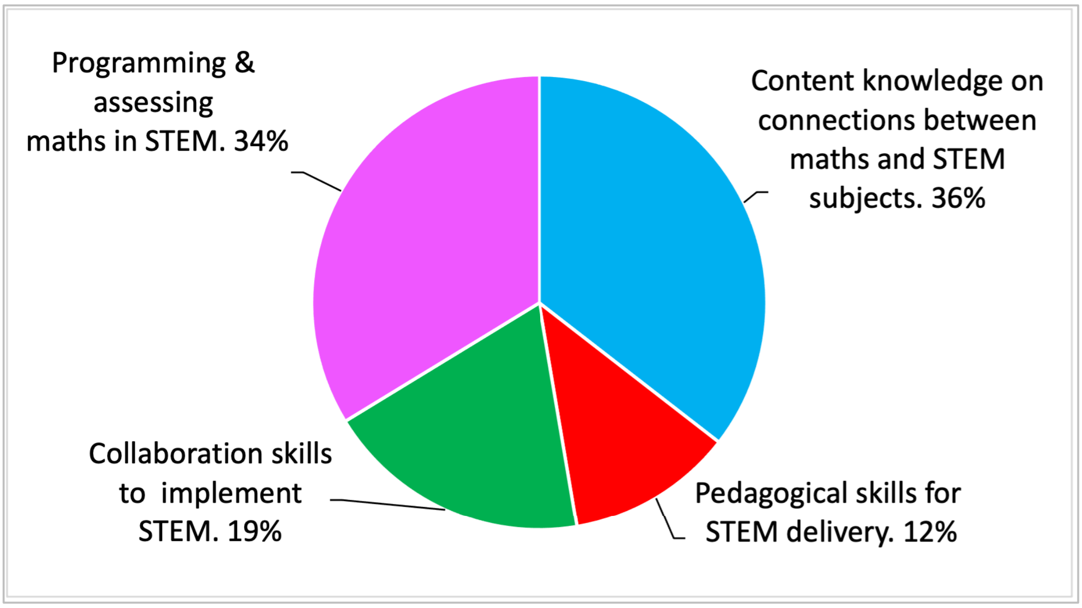
> Many concepts difficult to show direct use for as they are more building block concepts, e.g. simplifying algebraic expressions etc. (R1)

The classroom mathematics teachers responding to the survey are not alone in these concerns, as observations from tertiary educators, external providers and the regulatory environment demonstrate.

> I haven’t seen a lot of really great STEM activities or things happening in school. So I’m really strong in a math’s content, the maths might be there, but it’s often at a lower level than the year level that the kids are at. And it’s a bit tokenistic. (TE1)
>
> “It is quite challenging to find a place (implementing a STEM program) where students are not doing very basic measurement or number (TE3)
>
> … in a lot of integrated STEM projects… you could see there are trivial maths applications because people are trying to tie it back to the curriculum… when I was saying that the mathematics is trivial, the actual content itself, the mathematical content itself is trivial. (REG2)
>
> They (maths teachers) felt that the maths content in the STEM project was shallow and didn’t fully engage with the maths curriculum, tended to be just basic measurement or tokenism, that was a word that was used. (ESA1)

The low difficulty level and repetitive nature of mathematics content in existing STEM programs has been noted above. However, mathematics teachers themselves found it challenging to program mathematics into an integrated STEM project to the extent needed to satisfy the full scope and depth of curriculum outcomes in the faculty programs and assessment schedules. This challenge is exacerbated by the lack of subject content knowledge of STEM connections. These concerns are highlighted by programming and assessing mathematics outcomes in STEM together with learning about the connections between mathematics and STEM subjects being in highest demand for professional development (Figure 11).

Figure 11. *Demand for Professional Development for STEM (n = 47)*[76].



The nature and duration of professional development requested by mathematics teachers emphasised their perceptions of the complexity of learning about STEM for mathematics. The preferred duration and format were long-form (one to five days) workshops conducted in a small group format or on-

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[76] Question 28 of the Web Survey (n = 47).

line[77]. Classroom-ready resources were also in demand, reflecting earlier concerns about the lack of useful resources for mathematics in STEM:

> PD time is not a concern. I would be more interested if teachers are given resources to implement and/or build on. (R17)
>
> Videos of FULL lessons where STEM has been conducted. I would rather watch a video, pause and take notes, rather (sic) than listen to a lecture. I am more open to listening to a lecture that summarises and emphasises certain things if I have seen how it can work in a school setting. (R50)

4.3.4. External providers of STEM programs do not focus on mathematics

As illustrated in Figure 11, there is demand for STEM resources that make meaningful connections between the other STEM subject areas and the mathematics curriculum. Searches on the STARportal website[78] for in-school STEM activities involving mathematics provided by external organisations yielded 73 results. These were then interrogated using provider websites for evidence of an actual focus on mathematics in terms of reference to mathematics content in *the Australian Curriculum for Mathematics* and the background of the presenters of activities, where relevant. The results are displayed in Figure 12.

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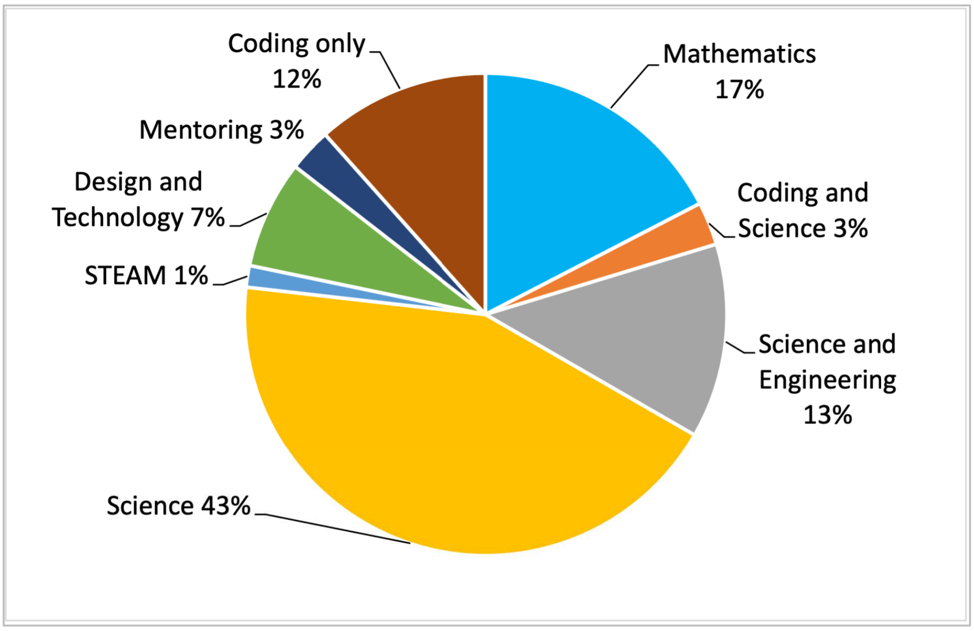
[77] Questions 26 and 27 respectively of the Web Survey (n =47 in both questions).

[78] https://starportal.edu.au/

Figure 12. *STARportal mathematics STEM activities showing actual focus area (n = 73).*



As is evident, very few STEM activities advertised as including mathematics actually did so in way that could be linked to the Mathematics curriculum. This confirms research that the inclusion of mathematics by external providers in STEM programs may be tokenistic. Survey respondents also expressed concern about the mismatch between content and stage level found in some STEM programs and the unfamiliarity of external providers of STEM programs for schools with the mathematics curriculum content.

> We had to teach content to Year 7 that was in the Year 8 program – not thought out at all. (R25)
>
> STEM designers often assume mathematics skills that are far beyond the level of the student they are teaching, e.g. expecting advance (sic) mathematics stage 6 skills in a stage 4 class. (R60)

4.3.5. Finding common content between the mathematics and science curriculums presents challenges

Finding content overlaps between the mathematics and science curriculums was challenging for mathematics teachers, as indicated by R1:

> It is difficult to find curriculum outcomes in both science and maths that can be used in the same program - not many links. (R1)

It has been suggested that statistics should be an area synergy between mathematics and science and provide opportunities for integrated learning (Dierdorp et al., 2014). As shown earlier in this chapter, data and statistics were commonly used mathematics components in STEM programs, in particular the collection and representation of data (MA4-19SP). Indeed, the stage 4 Science curriculum outcome SC4-7WS references the representation of data. However, closer inspection of the content statements accompanying the relevant outcomes in both curriculums reveals that the potential cross-over between these two outcomes appears to be narrow.

Prima facie, the mathematics outcome MA4-19SP is concerned with the collection, representation and interpretation of univariate data sets (Board of Studies NSW, 2012a, p. 29). However, the accompanying content statement in the Mathematics curriculum is extensive and prescriptive[79], conveying the breadth and depth with which data and statistics is approached in mathematics. Specific student outcomes encompass investigating techniques for collecting data and exploring the practicalities of obtaining data through sampling, in addition to constructing and comparing a range of data displays. The stipulated range of data displays must include frequency histograms and polygons, dot plots, stem-and-leaf plots, divided bar graphs, sector graphs and line graphs (Board of Studies NSW, 2012a, pp. 330-332). The skills comprised in SC4-7WS are specified in WS7.1b., WS7.1c.and WS7.2 b., whereby students process and extract data using a range of representations, including graphs, and analyse data by using a range of representations, including graphs (Board of Studies NSW, 2012b, p. 36). There is no further elaboration in the Science curriculum of content or student learning outcomes. To investigate the types of science classroom experiences which develop these skills and identify where there might be a connection between the curriculums, this study referenced the series of school science textbooks, *Science Essentials 7 for NSW* and *Science Essentials 8 for NSW* (‘*Science*

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[79] As an indication, there are 18 dot points and 20 dash points of prescribed content comprised in MA4-19SP (Board of Studies NSW, 2012a).

Essentials 7' and '*Science Essentials 8'* respectively) (Williamson & Garton, 2013a, 2013b).

In science, the recording and representation of data from experiments is clearly an important skill. Taking *Science Essentials 7* and *Science Essentials 8* together (as the stage 4 textbooks), there are 37 references to graphing activities, 28 of which involve constructing or interpreting a line graph derived from bivariate data. The terms independent and dependent variables are explained at length in the year 7 textbook, together with interpolation and extrapolation (Williamson & Garton, 2013a, p. 203), and lines of best fit are introduced (Williamson & Garton, 2013b, p. 110). However, in mathematics the construction of line graphs is only one application of the stage 4 mathematics content involving representation of data and the only consideration of bivariate data. As the focus in in stage 4 mathematics is on the features of the dataset distribution, such as measures of central tendency and spread, all other forms of data representation consider univariate data only. Bivariate data, along with scatter plots and lines of best fit, are not introduced in the Mathematics curriculum until stage 5, and then only for students studying the higher[80] curriculum pathways. Students in the lower[81] pathway are not introduced to bivariate data in mathematics at all.

Notwithstanding, it might appear that constructing line graphs from recorded data represents a cross-over opportunity between the curriculums. As both curriculums are silent on the actual construction of line graphs, further reference was made to *Science Essentials* together with three mathematics textbooks, *Cambridge Maths 8 NSW curriculum for the Australian Curriculum* ('*Cambridge Maths 8'*) (Palmer et al., 2015), *Jacaranda Maths Quest 7 Stage 4 Australian Curriculum* and *Jacaranda Maths Quest 10 5.2-5.3 NSW Australian curriculum* ('*Maths Quest 7*' and '*Maths Quest 10'* respectively) (Elms & Scott, 2017; Smith et al., 2018). Line graphs found in *Science Essentials 7* and *Cambridge Maths 8* are presented in Figure 13 for comparison.

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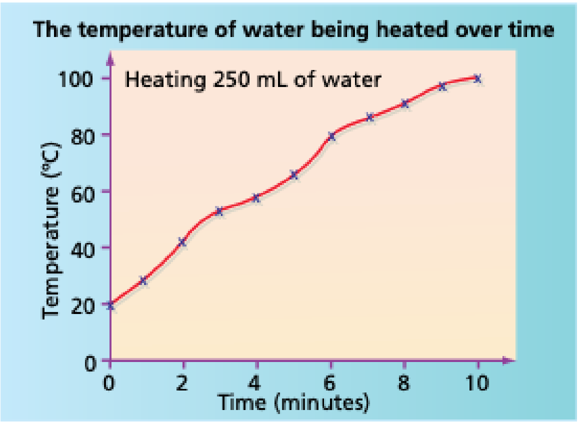
[80] Pathways 5.2 and 5.3 which are prerequisites for the calculus-based stage 6 courses.

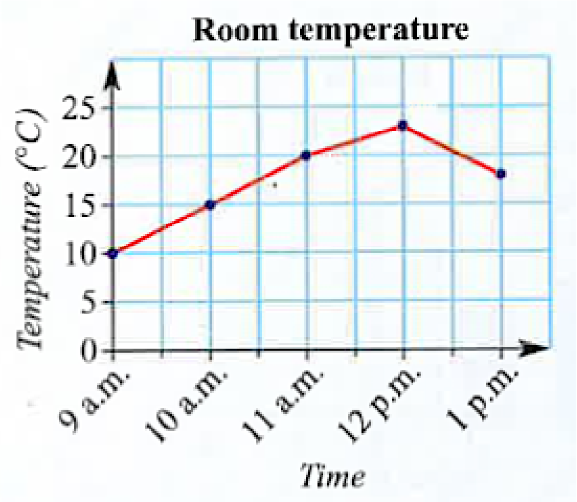
[81] Pathway 5.1.

Figure 13. *Comparing Line Graphs in Science and Mathematics*

Science (Williamson & Garton, 2013a, p. 29)



Mathematics (Palmer et al., 2015, p. 562)



Both line graphs record bivariate data with time as the independent variable. However, in the science graph each data point is indicated by a cross and students are instructed that the points (crosses) are "plotted correctly with a smooth curve connecting the points, not a straight line" (Williamson & Garton, 2013a, p. 29). In contrast, mathematics students are instructed to use dots for the data points, which are then "joined by straight line segments" (Palmer et al., 2015, pp. 561-562). This latter difference is important. In mathematics a line has a very specific algebraic and geometric meaning, as does the term 'segment', the definitions of which form part of the Mathematics curriculum (Board of Studies NSW, 2012a, p. 508). A line is always straight and interpreted algebraically by a linear equation. On the other hand, in science "it is quite common to talk about straight lines and curved lines" (Boohan, 2016, p. 8), and, depending on the data, it may be considered more correct in a line graph to join data points by a curve. A similar contrast arises with lines of best fit (Figure 14). Once again, in science such lines may be straight or curved. Determining whether a line of best fit for recorded data should be straight or curved in order to establish (or not) a causal relationship, and consideration of any underlying population variability, is an important skill for students to develop in science (Boohan, 2016, p. 90). In the Mathematics curriculum, students are explicitly instructed to construct a straight line using digital technologies (Board of Studies NSW, 2012a, p. 429). Variability in the data is noted but its significance is not discussed. Moreover, textbook exercises concerning lines of best fit in mathematics stress the characteristic of its 'straightness' by progressing to explore its properties in terms of constant gradient and linear equation (Elms & Scott, 2017, p. 618). These differences in construction conventions are not noted in either curriculum, nor is the 'content/standard' mismatch whereby bivariate data and lines of best fit are used in science in stage 4 but not introduced in mathematics until stage 5[82] (and not at all if a student is following the lower pathway).

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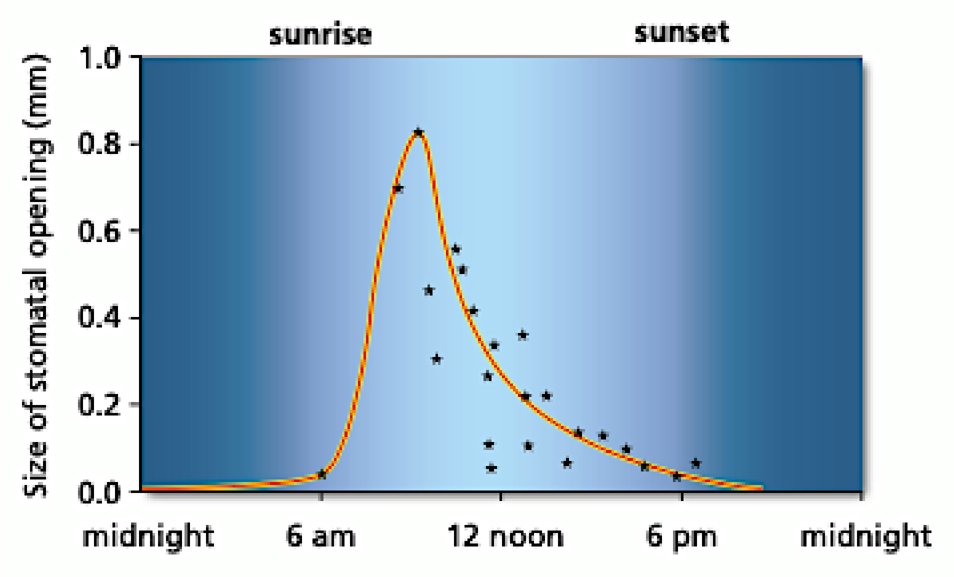
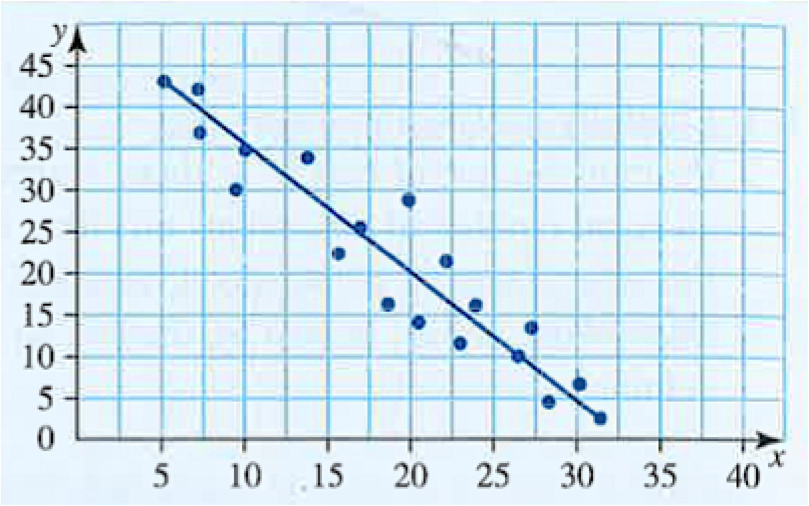
[82] Mathematics curriculum outcome MA5.3-19SP (Board of Studies NSW, 2012a)

Figure 14. *Comparing lines of best fit in science and mathematics*

Science (Williamson & Garton, 2013a, p. 110)



Mathematics (Elms & Scott, 2017, p. 618)



These differences between mathematics and science in conventions of construction and understanding, together with the place of bivariate data in the continuum of student learning, are indicative of the different approach to the same outcome taken by the different disciplines. The construction of bivariate data line graphs is a very minor aspect of the mathematics data and statistics outcome, which is introduced and then ignored until encountered again in stage 5 by some students only. However, the construction of line graphs in science is an important skill and an essential part of the Working Scientifically process, without which a student could not progress successfully through stages 4 and 5. When considering a possible cross-over in STEM programs, these differences create tensions in terms of fulfilling curriculum obligations for both subjects simultaneously as well as for transfer or application of student knowledge between the subjects.

The difference in stage location of bivariate data within the Science and Mathematics curriculums is an example of ‘content/standard’ mismatch (or, in the NSW context, ‘content/stage’ mismatch) identified by Meyer (2010). This is not an isolated occurrence. In the Mathematics curriculum, students in stage 4 encounter speed as a rate of travel and investigate its relationship to distance/time graphs[83]. Associated textbook exercises in *Cambridge Maths 8* use the formula for average speed as distance travelled over time (Palmer et al., 2015, p. 325) ($s = \frac{d}{t}$, or ‘the average speed formula’). In contrast, speed is introduced in the Science curriculum in the stage 5, where students “*explain the relationship between distance, speed and time*” (Board of Studies NSW, 2012b, p. 54). Once again, textbook exercises in *Science Essentials 10* use the average speed (or velocity) formula of distance travelled over time ($v = \frac{d}{t}$) (Williamson & Garton, 2013c, p. 151). The purpose of using the speed/velocity formula differs between the two curriculums. In the Mathematics curriculum, it is an *illustration* of a commonly used rate, located in the rates and ratios content outcome in the number and algebra strand. In contrast, in the Science curriculum its location forms part of the *content* concerning the motion of objects in the Physical World strand. In addition, and of equal importance, are the learning experiences provided by the relevant textbooks when rearranging the average speed formula (for example, making distance travelled the subject of the formula). In stage 5 Mathematics, students substitute into formulas to determine an unknown[84], using algebraic methods to change the subject when required. However, in *Science Essentials 10*, students are simply instructed to use the ‘triangle method’ (see Figure

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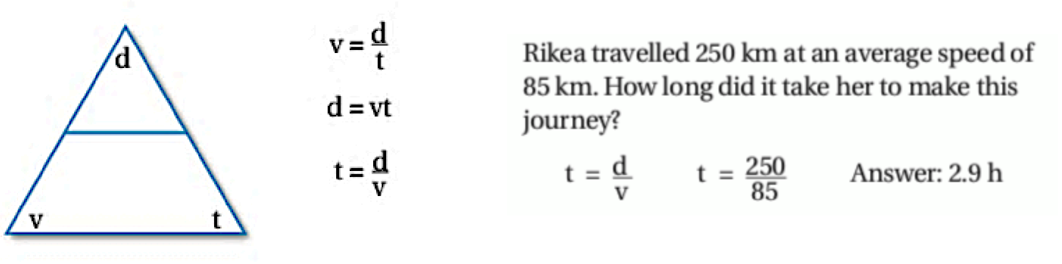
[83] Mathematics curriculum outcome MA4-7NA (Board of Studies NSW, 2012a)
[84] Mathematics curriculum outcome MA5.2-8NA

15) to change the subject of the equation, without reference to the application of students' mathematical knowledge[85]. The two learning experiences for rearranging the average speed/velocity formula are presented in Figure 15.

Figure 15. *Rearranging the speed/velocity formula in science and mathematics.*

Science (Williamson & Garton, 2013c, p. 151)



$v = \frac{d}{t}$

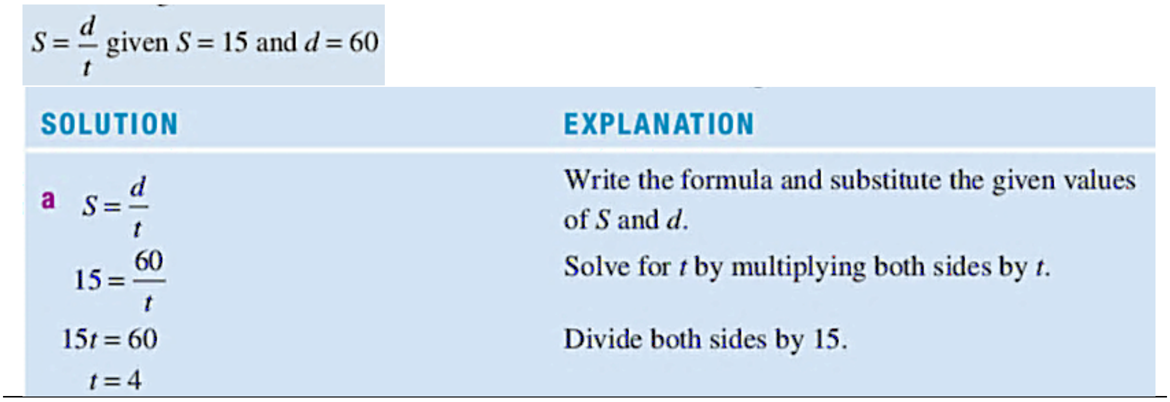
$d = vt$

$t = \frac{d}{v}$

Rikea travelled 250 km at an average speed of 85 km. How long did it take her to make this journey?

$t = \frac{d}{v}$ $t = \frac{250}{85}$ Answer: 2.9 h

Mathematics (Palmer et al., 2015, p. 325)



$S = \frac{d}{t}$ given $S = 15$ and $d = 60$

SOLUTION	EXPLANATION
a $S = \frac{d}{t}$	Write the formula and substitute the given values of S and d.
$15 = \frac{60}{t}$	Solve for t by multiplying both sides by t.
$15t = 60$	Divide both sides by 15.
$t = 4$	

Barriers to integrated STEM presented by a disjunction amongst the curriculums of content and lack of common approach to shared techniques are also acknowledged by the regulators.

> I've looked to try and integrate a STEM unit around some of the STEM share equipment that the department has rolled out, so these little ozo-bots, little robotics kits and looking at using them to study travel graphs and speed, distance, time kinds of calculations, but being science that's

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[85] The Science curriculum makes no mention of techniques to be used when determining any of the variables.

> related is actually a stage five component, as I was working through stage four mathematics. (REG2)
>
> …we need to get a better literacy about the terms we use, needs to become more consistent to make all those things more easier so that where a maths teacher refers to a mean … the TAS (Technology and Applied Science) teacher might refer to an average… And also, I think for different graphs, we need to have a common language so that when the maths teacher's talking about, it's the same words the science teacher's talking, and also the TAS teacher is talking. (REG1)

4.3.6. The nature of mathematics knowledge and learning is itself an obstacle to inclusion in integrated STEM programs

The dual nature of mathematics, being a tool which supports a vast array of human endeavours whilst at the same time being a "body of … knowledge for which no practical applications have yet been found"(Clark-Wilson & Ahmed, 2009, p. 7) was referred to in chapter 2 as raising a possible dissonance with integrated STEM programs predicated on interdisciplinary contextualised learning. This was alluded to by survey respondent R1 when referring to the lack of opportunity afforded in a STEM program to develop conceptual mathematical knowledge, as many concepts taught are "building block concepts", such as simplifying algebraic expressions, without a direct 'real world' application. This divergence between mathematics and the other STEM subjects in terms of contextualised learning was also recognised as problematic by regulators.

> …maths is the tool that we use in STEM education … So, while those other subjects are able to create those contexts easily, a maths teacher's left with actually still teaching the students the tool… (REG1)
>
> I just think it becomes much more time consuming for you to authentically place the maths in a STEM environment. (REG3)

The problem is compounded by the level of mathematical knowledge of students in stage 4, the years in which an integrated STEM program is popular[86]. In these years students are embarking on the 'building blocks' of algebraic thinking and are not mathematically equipped with more sophisticated tools which might be authentically utilised in a STEM program, such as non-linear functions and algebraic modelling. Whilst this may explain the low level of mathematics content typically found integrated STEM programs, it nevertheless presents mathematics teachers with the vexed situation of providing the M in a STEM program whilst being aware that there may be little or no development of students' mathematical knowledge. This is exacerbated by the nature of the mathematical toolkit commonly utilised – counting, measuring and collecting and representing data – which does not represent progress along a particular continuum within a curriculum strand or topic. As indicated by tertiary educator TE3, this may disrupt the overall mathematics program.

> I feel like the mathematics is kind of being lost in the STEM rather than being applied in the STEM…the maths program's lost. It's subsumed within STEM and it loses its own integrity. (TE3)

4.4. Indicators of change: sustainability of STEM education for mathematics.

As described in Chapter 2 (Section 2.4.2), The Levels of Use model (Bennett & Anderson, 2018; Hall, 1974) offers suggestions of indicators describing key changes in individual teacher behaviour that may indicate progress or otherwise along a continuum leading to the success of the implementation of a change initiative. In a non-mandatory change initiative such as STEM education, the challenge for individual teachers is to move personally and autonomously along this continuum. This requires a level of confidence, self-reflection and motivation to question the status quo, actively seek understanding and build internal capacity to incorporate the new ideas when making instructional decisions. On the other hand, not being mandatory offers

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[86] As noted earlier, in Years 7 and 8 (stage 4) in NSW all students study the same Mathematics curriculum.

the opportunity to rethink and reframe the ideas behind the change initiative. Working through this process can transform 'infectious enthusiasm' to informed conversations and create opportunities to expand internal capacity beyond the power of one, sustaining the innovation. As expressed by a tertiary educator:

> It takes a confident teacher to go out and make it work, because it's not just about doing it for your own class. In a way, you're trying to convince colleagues to be in on this, which means getting the head of department, maybe even getting your deputy principle or your principle on board. It's not something you can do by yourself. (TE4)

Indicators of change that emerge from the findings are indicate behaviour suggesting interest on the part of teachers in pursuing and/or adopting changes in professional practice anticipated by STEM education.

There is a recognition that STEM education can present an opportunity to revitalise mathematics teaching and learning. Mathematics teachers welcome STEM education as offering professionally stimulating and interesting teaching opportunities and appreciate that students are more interested and engaged in their learning. However, their experience reveals dissatisfaction with how the role of mathematics is conceived in STEM programs in terms of the scope and depth of mathematics content included.

> There is an amazing array of Maths in most subjects but programs both internally developed and externally provided seem to use Maths as a minor part of the course or project rather than the rich source of tools that could be used to develop and discover STEM concepts. (R38)

Rather than retreating to the status quo, mathematics teachers are interested in finding out how STEM education *can* work for mathematics and what they need to know to *make* it work. They acknowledge a lack of personal capacity both in terms of programming and assessing mathematics in a STEM environment and adequate subject content knowledge. Rejecting available programs and resources and lacking valid cross-over opportunities between the STEM curriculums, they demand high quality professional development and resources with valid and meaningful links to the mathematics curriculum.

However, low class-time contribution and amount and level of mathematics content in STEM programs, together with lack of assessment strategies and curriculums deficient in connection and consistency, present significant procedural barriers. Together, they suggest the fundamental characteristics of collaborative integrated or interdisciplinary learning within a design project structure, as promoted by research and the policy and regulatory environment, may not work for mathematics education in the NSW school environment. Instead, mathematics teachers demonstrate a willingness to re-imagine STEM education as taking place in the mathematics classroom, using examples from STEM subjects to enhance teaching and learning whilst at the same time fulfilling curriculum and programming obligations. This re-imagining is supported to an extent by the policy and regulatory environment via officer observations and the NESA STEM Pathways programs. Recognising STEM education for mathematics in this way is not necessarily a narrow interpretation. Difficulties encountered within the school structure in implementing a STEM project are well documented and thus this reframing may represent a more realistic and sustainable option for STEM education for mathematics. By reclaiming mathematics education within STEM, this understanding broadens its scope to meaningfully recognise applications in STEM endeavours and thus preserves an essential STEM feature of connected student learning. It also signifies engagement by mathematics teachers in STEM education endeavours, a willingness to look at new ways of teaching mathematics content. This engagement is expressed by survey respondent R65:

> …Most teachers who have only been teachers are often caught in the narrow confines of subject areas that high schools create. Really wide-ranging and creative ideas for students to understand the importance of maths are extremely important if the aims of STEM are to be achieved. (R65)

and at the urging of regulatory officer REG3:

> We need our teachers to be creative. We need them to not be afraid to take a leap into a space that's unfamiliar, because in them learning, their students are going to learn as well. (REG3)

4.5. Concluding remarks

This chapter presented the findings from analysis of the data generated from the web survey, semi-structured interviews and document analysis. Presenting the analysis using areas of importance for STEM education for mathematics identified in the literature, themes emerged pertaining to these areas from the data across the various stakeholder groups representing the policy and regulatory environment, mathematics teachers, tertiary educators of pre-service mathematics teachers and external providers of STEM advice and programs for secondary schools. These themes confirmed existing research. The understanding of STEM education as an integrated and interdisciplinary collaborative effort between STEM disciplines is supported by formal statements from the policy and regulatory environment. Concerns expressed in literature about mathematics content in integrated STEM programs resonated with mathematics teachers, tertiary educators, external STEM advisors and regulators. These concerns were validated by analysis of STEM programs, confirming that mathematics in STEM programs privileges low level, process-driven outcomes. Furthermore, analysis of external STEM programs also confirmed a dearth of resources with a meaningful focus on mathematics offered by external providers.

However, there were also considerable divergences, challenging the assumptions underlying implementation of the STEM school education agenda. Firstly, despite formal pronouncements on websites, the position of the regulatory environment is not clear. The promotion of STEM education as a complementary and equal collaborative effort amongst the three disciplines is undermined by the characterisation of a STEM program as necessarily involving the design and/or production of a physical object. This apparent location of STEM programs within the Technology curriculum effectively integrates the other STEM subjects within that subject, fulfilling outcomes and mandatory assessment requirements of the Technology curriculum. This raises questions about the efficacy of the class-time contribution of participation in a STEM program by mathematics in terms of its own curriculum obligations and the nature of collaboration envisaged. The NESA STEM Pathway programs provide an additional counterpoint, being neither integrated nor relying on interdisciplinary collaboration for implementation. This conflicting scenario is acknowledged by regulators.

> …there is…a contradiction between what the regulatory environment states to be their position on STEM via website(s) and what they recognise is possible within schools. They need to embrace this more holistic and realistic viewpoint…would lead to less confusion. (REG3)

Curriculum constraints in terms of language, conventions and content staging and practices also emerged as a significant theme, challenging assumptions of complementary interdisciplinary learning in STEM education. Additionally, references by regulators suggested that meaningful inclusion of mathematics learning in integrated STEM programs may be precluded by the nature of mathematics knowledge and the structured continuum of student learning in mathematics. This creates uncertainty about the overall role of mathematics education in a STEM program and whether it will indeed lead to the increased achievement in mathematics as envisaged by the NSSES. Perhaps as a consequence of these factors, together with confusion and lack of understanding of what was envisaged by the STEM education model promoted by the regulators, a divergent understanding of STEM education for mathematics emerged amongst mathematics teachers in this project. Whilst acknowledging the benefits of STEM education to teachers and students alike, mathematics teachers envisaged STEM education located within the mathematics classroom and curriculum, reaching out for interdisciplinary input reconstructed within the continuum of mathematics learning.

Taken together, the divergences suggest implementation of STEM education for mathematics in NSW may have deviated from any model originally envisaged by the regulatory environment, as admitted by a regulatory officer.

> I think in the launch of STEM as a national priority and then putting that into schools, there have been many, many steps that have been missed along the way in supporting teachers to shift the culture of how we

> teach mathematics in schools. … It hasn’t helped them to catch the vision of the STEM by skipping all of those steps. (REG2*)*

With reference to the relevant literature, these convergences and divergences will be discussed in chapter 5 in the context of interrogating the assumptions of STEM education for mathematics and the operational validity and coherence of such assumptions in NSW secondary schools. Through the lens of policy and change, discussion will explore what is understood and enacted as teaching mathematics in a STEM environment and to what extent these actions and understandings represent an effective change model for mathematics education in NSW secondary schools.

Chapter 5. Discussion of findings

This research sought to understand how the STEM education agenda in NSW was perceived and experienced in the mathematics classrooms of secondary schools in NSW. Under the Australian *National STEM School Education Strategy 2016-2026* (NSSES) (Education Council, 2015), NSW education regulators were tasked with broad functional responsibility to implement actions in accordance with two overall goals. In common with school STEM strategies world-wide, the goals were to increase the STEM knowledge and skills of Australian school students together with the number of students selecting advanced STEM subjects in senior school. It is within the ambit of this responsibility, together with the boundaries of the Australian and NSW curriculum framework, that the landscape of STEM education in NSW schools has developed. The previous chapter described the key findings of this research, gained by listening to the voices of major stakeholders in STEM education in NSW – state education regulatory authorities, external STEM advisors and providers of STEM education programs to secondary schools, tertiary educators of preservice mathematics teachers and mathematics teachers themselves, together with analysis of key documents. Divergences and convergences between these voices drew attention to both the assumptions underlying the implementation success of the NSW strategy and the attitude of individual mathematics teachers towards STEM education. Together, these findings offer insight into the reception and sustainability of STEM education in the mathematics classroom in NSW secondary schools.

This chapter discusses the findings and their contribution to understanding STEM education for mathematics beyond the vision of a policy document to respond to the original research questions, namely:

1. What is understood and enacted as mathematics teaching and learning within a STEM education model in NSW secondary schools?
2. To what extent does this approach to STEM education represent an effective model of change for mathematics education in NSW secondary schools?

This chapter begins with a summary of the key findings and follows with a discussion guided by the four dimensions of enquiry identified in the literature (see Table 1 in chapter 3).

5.1. Key findings

The divergence between the perspective of STEM education endorsed and promoted by the regulatory environment and that of other stakeholders was stark. The policy statements of the regulatory authorities promoted a model favoured by research, that of integrated or interdisciplinary curriculum learning comprising the component subjects and delivered as a design project. On the other hand, mathematics teachers envisaged STEM education as connected learning located within the mathematics classroom, rather than necessarily an interdisciplinary endeavour.

Tertiary educators and external STEM advisors saw little evidence in practice of the regulator's vision and external providers of STEM education programs barely registered an interest in mathematics in their STEM education programs. In implemented STEM programs, provided as exemplars by the regulatory authorities, the technology curriculum emerged as the host vehicle, raising questions about the role of mathematics and the epistemological foundation of STEM. Findings that the mathematics typically used in these programs privileges low level, utilitarian outcomes confirmed existing research in the context of NSW secondary schools and questions the value of popular conceptions of STEM programs to mathematics education. Tensions arising between STEM curriculum documents in terms of language, conventions and content staging emerged as a significant dissonance in the implementation environment. This dissonance speaks to the common but unresolved position of implementing interdisciplinary or integrated STEM programs within subject-specific education systems.

Taken together, these divergences and dissonances suggest that sustaining changes in curriculum delivery envisioned by the integrated STEM model promoted in NSW is questionable for mathematics education. However, a more positive prospect lies in the divergent understanding of STEM education for mathematics that emerged amongst mathematics teachers. Acknowledging the benefits of the ideas and aims of STEM education to teachers and students alike, mathematics teachers sought practical content and pedagogical support to engage students in connected learning in the mathematics classroom. This suggests an openness to implementing change on the part of mathematics teachers as individual teachers, rather than necessarily as part of a large-scale collaborative effort. Envisioning STEM education located within the mathematics classroom and curriculum and informed by interdisciplinary content may simply be a more pragmatic approach to achieving the aims of the NSSES within the constraints of the school environment and the structure of the education system as a whole. Somewhat confusingly, this perception of STEM education as achievable solely within the mathematics classroom, involving connecting mathematics learning with the other STEM disciplines (and beyond) *without any form of integrated learning* approach, appears to receive support from the regulatory environment[87].

5.2. What is understood as STEM education?

As noted in Section 5.1 above, the understanding of STEM education expressed by mathematics teachers in this study diverged from the model promoted by the regulatory environment. This section explores this divergence by examining the assumptions underlying the implementation success of the regulatory model in light of the findings from this research.

5.2.1. Regulatory vision of STEM

The model of STEM education promoted by the NSW Department of Education (DoE) and its regulatory authority, the NSW Education Standards Authority (NESA), features key characteristics of much of the research in this field (see, for example, English & Kirshner, 2015; Moore & Smith, 2014). It describes delivering curriculum learning in all three of the NSW STEM disciplines (Science, Technology and Mathematics) using fully integrated or interdisciplinary[88] (these terms are used

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[87] See Section 4.1.2 for a description of the STEM Pathway programs for mathematics and a comment from the regulatory environment. These curriculum programs are not available for the other STEM subjects and do not include curriculum outcomes from these subjects.

interchangeably) units of work involving the development and production of a design project (Section 4.1.1). This strategy was communicated to educators via dedicated STEM webpages, providing resources in the form of exemplar units of work and a broad framework of advice for planning and developing an integrated STEM unit of work. The strategy did not provide an explanation of the choice or benefits of an integrated STEM model, nor was mention made of *a priori* implementation considerations such as resourcing, professional development, curriculum implications, timetabling or time commitment for planning, despite such considerations being well documented in the literature (see, for example, Honey et al., 2014; Stohlmann et al., 2011). In other words, assumptions underlying successful implementation linking the strategy to the intended outcomes were left implicit. Instead, the strategy presents the regulatory vision rather than a roadmap to arrive there.

Missing steps were acknowledged by a regulator as preventing teachers in catching the 'vision of STEM' (see Section 4.5). Literature consistently records the failure of regulators to provide educators with adequate clarity of the rationale and explanation of causal assumptions underpinning reforms, in the belief that communicating a broad and loosely connected vision is sufficient and teachers and schools will both understand what is intended and be ready, willing and able to implement (Connolly & Seymour, 2015; Fullan, 2016; Jackson, 2019; Weiss, 1995). This study agrees with the analysis of Murphy et al. (2019) in confirming that the NSW strategy gave "minimal description" (p. 132) of how and why an integrated model was chosen. Regulators assumed that not only did teachers *understand* what integrated or interdisciplinary STEM education was, but also that they were adequately *prepared* in terms of knowledge, pedagogy and resources to implement such a program in their school environment. Further, schools were assumed to be 'STEM ready' in terms of the specific *pre-existing* conditions that are required in the *whole-school environment* in order to embark on a successful integrated STEM program. An additional, and fundamental, assumption was that educators would be able to *align* an integrated

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STEM program with the overall structural requirements of the NSW education system, as is required of any school program delivering in-curriculum learning (as distinct from extra-curricular or optional programs). These assumptions are central to understanding the divergences that emerged or were observed amongst stakeholders in their understanding of STEM education in NSW secondary schools.

5.2.2. Confusion, complexity and capacity: divergent visions of STEM in schools

STEM education is notoriously difficult to define, and its understandquing is further complicated by the very different use of the term in the public and political arenas and that of the education research community. In the former, STEM education refers simply to education in the component disciplines and its use is tied firmly to employment and economic goals. In the latter, it is understood as the latest iteration of pedagogies associated with some form of integrated or interdisciplinary learning, with a long and controversial research history. It is not surprising that educators struggled to comprehend what STEM education meant in the school environment, as admitted by a head teacher: “I was confused. I think, when I looked at other people, I kind of got the sense that, it was different things, for different people” (HT3 in Section 4.1.2). Although the regulatory use of the term conformed to the academic standpoint, the diverse examples of STEM programs described by teachers of mathematics (Section 4.1.2) speak to a blend of understandings informed by both public/political and education perspectives. STEM programs described in their schools ranged from stand-alone enrichment days, participation in some type of STEM-branded external program and school ‘STEM clubs’ (robotics and coding). Another described adapting external resources for use in the mathematics classroom and some admitted to giving up in the face of the complexity of the task ahead. Student accessibility to STEM programs was also an issue (R16 and ESA1 in Section 4.1.2) and often limited on the basis of ability. Mathematics teachers who had been involved in implementing integrated STEM programs also expressed confusion about what they *thought* STEM education should look like, and what they *experienced* in the program (Section 4.1.2), where mathematics was incidental to what appeared to be a technology design or science project. On the other hand, external providers of STEM programs appear to interpret STEM education as referring only to science, with little, if any, reference to mathematics (Section 4.3.4). Observations from tertiary educators and regulators confirm that this understanding of STEM education as primarily involving science or technology, at the expense of mathematics, is widespread in NSW schools (Section 4.2.1) and indeed across STEM programs in secondary schools in general (Hayward, 2016; Lasa et al., 2020; Martín-Páez et al., 2019).

This focus on STEM education as technology or science also reveals a lack of understanding of what is meant by the terms ‘integrated’ or ‘interdisciplinary’ in the NSW STEM strategy. These terms have a long history in education research, but are by no means common parlance in schools (Drake & Burns, 2004), and, in any event, teachers rarely turn to research literature for guidance, relying instead on information provided by regulators (Colley, 2020; English & Kirshner, 2015). Studies have consistently shown that teacher recognition and characterization of what constitutes integration differs from models of integration proposed by researchers and expressed in educational reform documents (for example, Meyer et al., 2010; Wang et al., 2011; Weinberg & Sample McMeeking, 2017) and a common understanding amongst educators themselves is rare (Munro, 2017). As Spillane (2009) observes, the sense made of a new policy in schools depends on educators’ existing understanding, and policy makers mistakenly assume that they and educators share the same understanding. The confusion and divergence of understanding experienced in response to the NSW STEM policy indicates that educators simply did not understand what was being communicated and what they were meant to do. It is not surprising that mathematics teachers found navigating the meaning and implementation of STEM education in NSW bewildering, particularly for mathematics, and might echo educators Akerson et al. (2018): “If we were supposed to teach STEM, then there should be some indication of what STEM would actually be“ (p. 2).

Baptista et al. (2020) point out that it is common for the grey literature of policy and strategy statements to use academic language to communicate to a public audience, without explanation or clarification. In the face of the intense and prolonged debate in academic circles over an agreed definition of STEM education and the plurality of frameworks advocated, any attempt to explain or clarify on the part of the NSW regulators might be considered formidable, and indeed, the NSSES took a similarly opaque approach by referring to STEM education as teaching in the component disciplines as well as involving “cross-disciplinary” and “integrated and project-based” approaches (Education Council, 2015, pp. 3, 10). Nevertheless, the conundrum remains – a particular model of STEM education was advocated for implementation in schools which was poorly understood by the implementing audience and which defies clarification. This lack of a common perception has been widely and consistently identified as one of the most serious barriers to the acceptance and implementation of STEM education (Breiner et al., 2012; Herschbach, 2011; Holmlund et al., 2018).

Notwithstanding the lack of definitional clarity, there *is* research consensus concerning the actions required in the school environment in readiness for an integrated program, together with the ongoing demands of implementation (see Czerniak et al., 1999; Honey et al., 2014). These actions include timetabling to deliver integrated classes and for teachers to collaborate and plan, together with increased demand for concrete resources, physical space and technology. Timetabling and resourcing are school-wide decisions, generally made a year in advance and in competition with other priorities and needs. The breadth of adjustments needed, together their impact on non-STEM faculties, suggest that the decision to introduce an integrated STEM program is not taken lightly and that careful planning and negotiating would be required well ahead of time. These factors were confirmed in this study as challenges in the whole-school environment in implementing integrated STEM (Figure 9 in Section 4.3.3), suggesting that the schools were administratively unprepared. Notwithstanding these considerations being consistently and unambiguously affirmed in research, none are acknowledged in the broad advice provided on the NSW strategy pages for schools planning a STEM program.

The final assumption discussed in the section[89] that underpins the NSW STEM strategy and is considered in this research is that teachers were adequately prepared to teach in an integrated or interdisciplinary STEM program. Teacher capacity in the

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[89] The assumption that educators would be able to *align* an integrated STEM program with the overall structural requirements of the NSW education system is part of the broader discussion of curriculum challenges to integrated STEM program and is considered in Section 5.3.3.

classroom is consistently nominated as the single most critical factor for the success of any education reform such as integrated STEM programs (Honey et al., 2014; OECD, 2015; Pearson, 2017). To successfully deliver integrated STEM, teachers need to broaden both their content knowledge to gain a deeper knowledge of curriculum connections, together with developing pedagogical approaches to manage group-based learning and engender collaborative and creative approaches to problem-solving (Berlin & White, 2012; Capraro et al., 2016; Honey et al., 2014; Margot & Kettler, 2019). Collectively, the expertise required of a confident and effective teacher in an integrated STEM environment represents a significant departure from the traditional, single-discipline approaches in which teachers have been trained and may have considerable expertise (Falloon et al., 2020; Margot & Kettler, 2019).

The lack of such expertise is commonly reported by secondary teachers as a barrier to teaching in an integrated STEM environment (Margot & Kettler, 2019; Weinberg & Sample McMeeking, 2017), a sentiment shared by mathematics teachers in this study (Figure 11 in Section 4.3.3). Developing such knowledge and expertise requires sustained professional development. By way of example of what is required, Tytler et al. (2019) describes a series of intensive workshops followed by a lengthy period of in-school mentoring and consultation provided to teachers in two successful university-led STEM education programs. The perceived complexity of the effort required was communicated by mathematics teachers in this study in their preference for long format, small group ‘hands-on’ workshops (Section 4.3.3). Mathematics teachers wanted to know *how to develop* STEM programs for mathematics and what integrated STEM would look like *in the classroom* so they could adopt, adapt and develop new strategies to suit their local environments, as emphasised by teacher R50: “Videos of FULL lessons where STEM has been conducted… I am more open to listening to a lecture that summarises and emphasises certain things if I have seen how it can work in a school setting.”

Perceptions of lack of adequate or appropriate content knowledge and pedagogy are not the only limitations on teacher capacity in integrated STEM programs (Section 4.3.3). High-quality, classroom resources such as videos, guidance documents and lesson plans linked to curriculum standards are also required to initiate and progress reform (Groves et al., 2017; OECD, 2015; Williams et al., 2016). As has been the experience in numerous studies in many jurisdictions (see Lasa et al, 2020, Martin-Páez et al, 2019 and Margot & Kettler, 2019), mathematics teachers in NSW struggled to include meaningful mathematics in a STEM program and were unable to source materials that did so (Section 4.3.3). Comments emphasised both the small amount and insubstantial nature of mathematical procedures included in programs to which they were exposed. ‘Trivial’, ‘tokenistic’ and ‘insubstantial’ were used by *all* stakeholder groups interviewed when referring to the mathematics content in an integrated STEM program. Finding or programming resources linking mathematics both to and in sufficient depth to satisfy curriculum standards was nominated as the greatest challenge facing mathematics teachers in NSW in implementing an integrated STEM program (Figure 10 in Section 4.3.3), a challenge consistently confirmed by research (Australian Curriculum Assessment and Reporting Authority [ACARA], 2016; Meyer et al., 2010; Wang et al., 2011). To accompany the NSW strategy statements, regulators published exemplar STEM programs implemented in schools and sample STEM units of work. Analysis of these programs show that the mathematics included was largely confined to calculation, measurement and collection and display of data, areas largely requiring the application of techniques rather than conceptual development, and insufficient to fully satisfy curriculum standards (Figures 5 and 6 in Section 4.2.2). This analysis, together with the analysis concluding that little or no mathematics was included in externally available STEM programs (Section 4.3.4), underlines the frustration felt by mathematics teachers in seeking to deliver curriculum outcomes within the ambit of the NSW strategy.

The discussion above has highlighted how the reception and implementation of the regulator’s vision of STEM education as an integrated model of curriculum delivery was met with a confused understanding and apprehension of lack of capacity by the mathematics teachers, together with a lack of awareness of the complexity of implementation within the whole-school environment and curriculum framework. Adopting an integrated STEM education approach is a fundamental change in whole-school pedagogy. The scale of the effort is exemplified by the example of highly successful integrated learning at Parramatta Marist High School (PMHS) in Sydney, NSW. Effecting this change has included intensive and sustained teacher training, gaining access via an international network to proven high-quality classroom resources, timetable restructuring and redesign of physical learning spaces (Hendry et al., 2017; Hendry et al., 2016). Whilst a more explicit definition of integrated STEM education may not have been useful nor possible, investigation of the research-validated in-school considerations to be taken into account prior to establishing an integrated STEM program may have assisted regulators in formulating a vision for STEM education that was both realistic and accessible to NSW secondary schools.

5.2.3. Envisaging the possible: STEM in the mathematics classroom

It is notable that the NSW strategy did not envisage that individual teachers might seek to access and implement small-scale activities using ideas from STEM education. Notwithstanding the difficulties encountered when implementing an integrated STEM program in the school environment, the benefits of teaching and learning in a STEM environment to *both students and teachers* alike were recognised by the mathematics teachers in this study (Section 4.3.2). They enjoyed expanding their subject content knowledge to understand the connections to and use of mathematics in other subject areas, or “the opportunity to see outside their own subject area” (R29, Section 4.3.2), and sought professional development to enable them to do so. In response to this belief in the value of STEM education, together with the lack of clarity and direction provided by the regulatory position, an alternative perception of the possibility of STEM being situated *within* mathematics emerged from mathematics teachers. Specifically, this perception understood STEM education for secondary mathematics as using examples from the other STEM subjects to make connections with the students’ learning in mathematics where relevant (Figure 3 in Section 4.1.2).

This vision of STEM resonates with Akerson et al. (2018), who, as a science teacher, asks “Do we need to connect all of the other STEM disciplines to have a good lesson?” (p. 6). Research confirms that teachers will tend to privilege their own subject area (Bell, 2016; Bingham, 2016; Cinar et al., 2016; Weinberg & Sample McMeeking, 2017) and mathematics teachers have been thought to show a degree of resistance to STEM education (Rogers et al., 2011; Stohlmann et al., 2011; Wang et al., 2011). However, rather than signalling a wholesale rejection of STEM education, mathematics teachers may instead be expressing a pragmatic approach to negotiating a pathway though curriculum responsibilities on the one hand and, on the other, improving student engagement and achievement. The STEM Pathway programs for mathematics subsequently released by NESA support this more flexible vision (Section 4.1.2). Appearing to pivot from the official vision of integrated STEM, these materials connect curriculum learning in mathematics with cross-discipline opportunities[90] (beyond technology and science) that may be fulfilled entirely within the mathematics classroom. Indeed, the recognition of STEM education as achievable solely within the mathematics classroom was validated again in the regulatory environment by the words of REG3: "…if we're working just in the mathematics classroom, again, the key characteristic is students having the opportunity to connect to the learning that they're doing in that classroom to areas outside." (Section 4.1.2). Tytler (2020) speaks along similar lines when he describes the opportunity of realigning "mathematical thinking and working to real-life, complex, problem-oriented contexts" (p. 35) whilst maintaining the distinct disciplinary practices of mathematics. This allows for the introduction of authenticity naturally into mathematics learning without disturbing learning progressions and focuses on mathematics learning as *enabling*, a feature widely acknowledged to increase student engagement. Importantly, such small-scale activities are accessible to all mathematics classrooms. As an example of this approach, Bowen and Peterson (2019) describe an engineering based activity carried out within the mathematics classroom to introduce the concept of slope and y-intercept.

5.3. Mathematics in the STEM classroom

Typically, integrated STEM programs include little or no mathematics content and such content favours low skill-level, process driven procedures that preclude the fulfilment of the formal requirements of a mathematics curriculum. This feature of STEM programs is universally recognised in research (Hayward, 2016; Lasa et al., 2020; Margot & Kettler, 2019; Martín-Páez et al., 2019). It is also confirmed by *every*

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[90] Connections to other disciplines are not linked to curriculum outcomes in those disciplines and indeed extend beyond school-based disciplines

stakeholder group in this research (Section 4.3.3), from mathematics teachers themselves: “Very low level of maths…only required basic statistics” (R43), tertiary educators: “It is …challenging to find (a STEM program) where students are not doing very basic measurement or number” (TE3), external STEM advisors: “the maths content in the STEM project was shallow” (ESA1) through to regulators themselves: “in a lot of integrated STEM projects…the mathematical content itself is trivial” (REG2). Additionally, literature widely acknowledges that it is more difficult for mathematics teachers than other STEM teachers to program mathematics into an integrated STEM program (see, for example Australian Curriculum Assessment and Reporting Authority [ACARA], 2016; Clark-Wilson & Ahmed, 2009; Martín-Páez et al., 2019), a challenge also confirmed by mathematics teachers and regulators in this study (Section 4.3.3). That these shortcomings of integrated STEM programs continue to be widely and persistently reported should be of concern to researchers and regulators alike. The historical impetus for both political and research interest in STEM education was declining mathematics achievement at secondary school level and enrolments in STEM-focused tertiary studies. The two are inextricably linked, as achievement in advanced secondary mathematics is a benchmark both for entry to and success in tertiary STEM education (Hoyle, 2016; Nicholas et al., 2015). It is ventured that there is no STEM education policy worldwide that supports the notion that mathematics is incidental and trivial and indeed, in the Australian context, the NSSES singles out mathematics as underpinning all STEM learning (Education Council, 2015). It is necessary, then, to consider whether there are fundamental features of integrated STEM programs that lead to this disconnect between integrated STEM and mathematics.

5.3.1. *The role of mathematics: value in the integrated STEM transaction*

Both regulators and tertiary educators observed that integrated STEM programs implemented in schools appeared to be ‘grounded’ or ‘aligned’ with science or technology (Section 4.2.1). Analysis of the STEM Project documents located enacted STEM programs in NSW primarily within the technology curriculum (Section 4.2.1), whilst external providers favoured science-based STEM programs (Section 4.3.4). In no case is mathematics recognised as the lead discipline and mathematics teachers lamented the small amount and low level of mathematics learning included in the integrated STEM programs in which they had been involved (Section 4.3.3). Together, these findings confirm research that one STEM discipline usually dominates over the others in an integrated STEM program, notably either science or technology (English, 2016b; Groves et al., 2017; Honey et al., 2014; Martín-Páez et al., 2019). Mathematics is consistently relegated to a supporting role only, both in terms of the amount and type of mathematics content included.

Brophy and Alleman (1991) urge educators to weigh the cost-effectiveness of introducing activities that may not be educationally significant in terms of a subject's learning goals and progressions. Whilst using economic terms in discussions of teaching and learning is unusual, it is not inappropriate in the *realpolitik* of the school environment, where the 'scarce resources' of teacher and student class-time must be allocated so that curriculum outcomes are delivered within the timespan allowed by the curriculum program. Implementation of an integrated STEM program can be viewed as a transaction between the participating disciplines, where teacher time, both in planning and active participation, as well as subject class-time, are contributed to the program in exchange for the meaningful inclusion and satisfactory student progress in curriculum outcomes from each of the participating subjects. Taking a transactional approach allows focus on the *role and purpose* of mathematics in integrated STEM and highlights concerns that have emerged about the balance of representation of disciplines and the distribution of discipline learning (Baldinger et al., 2020; English, 2016a; Maass et al., 2019).

The supporting role of mathematics in integrated STEM suggests that the *benefits* of participation in an integrated STEM program are not equally distributed in terms of the *value* of the mathematics learning envisaged. Both in this study (Section 4.2.2) and in the literature, the mathematics content included in integrated STEM programs has involved largely lower-level procedural aspects of curriculum learning, rather than the higher-order mathematical thinking necessary to fulfill curriculum objectives. In NSW, integrated STEM was characterised as technology design-based learning (Section 4.1.1 and Section 4.2.1). This characterisation, popular in the literature (see Doig & Jobling, 2019; Havice et al., 2018; McComas & Burgin, 2020; Wells, 2013, 2016), automatically limits the scope of possible applications of mathematics to those relevant to the design and production process, typically calculating, measuring and collecting and representing data. Limiting mathematical involvement in an integrated STEM program to a repetitive set of skills-based outcomes, without opportunities *within the coherence of the program* to develop mathematical thinking beyond these trivial applications, raises the question of whether this involvement is as beneficial to mathematics as it is to technology. As the findings show, an integrated STEM program conceived as design project can accommodate the full range of technology curriculum outcomes and assessment requirements (Section 4.2.1). The value to mathematics is considerably less in terms of student learning goals, curriculum progression and assessment opportunities (Section 4.2.1). In terms of a cost-benefit analysis, the contribution made of teacher and student class-time may in fact be a *deficit* to mathematics if mathematics curriculum progressions are compromised and student learning undermined, as has been cautioned by literature (Australian Curriculum Assessment and Reporting Authority [ACARA], 2016; Maass et al., 2019; McComas & Burgin, 2020). In other words, an integrated STEM program characterised as technology design-based learning may not represent value to mathematics learning in the school environment.

On the other hand, it must be considered whether including mathematics as a distinct discipline represents value to this type of integrated STEM program. The commonly utilised curriculum outcomes for mathematics in the integrated STEM programs considered in this study were found to be number, measurement and statistics (Section 4.2.2). Specifically, the focus was on operations using spreadsheets (for costing), ratios to scale a design, calculating perimeter, area and volume and the collection, display and interpretation of single variable data. These are common with the mathematics identified in integrated STEM programs in the literature (Australian Curriculum Assessment and Reporting Authority [ACARA], 2016; Berlin & Lee, 2005; Wang, 2012). They are also procedures, whether recognised as ‘mathematics’ or not, *already embedded* either by reference in technology and science curriculum documents (for example, data skills) or in everyday classroom procedures. It is difficult to imagine designing and constructing an artefact in technology without needing to scale and measure, or investigating the results of an experiment in science without recording, representing and interpreting data. Furthermore, the analysis of curriculum documents in the findings demonstrated that these procedures may be performed in another subject without drawing on or developing understanding of underlying mathematical concepts[91]., as was seen with the use of the formula for speed and distance in science (Section 4.3.5). Additionally, different terminology, forms of representation and conventions may also be used, as was found with graphing in science (Section 4.3.5). Whilst these procedures represent overlaps between the curriculums, they also show how highlighting this mathematics may be incidental to the overall progress of the STEM program *as students would have performed them regardless.* Hayward (2016) and Lasa et al. (2020) observe that the nature of mathematical activities in technology/engineering or science focused STEM programs is often optional, and students can and will use their own strategies and trial-and-error, without resorting to any formal mathematics to progress through the project. In other words, the *value* of including mathematics as a specifically nominated discipline in such integrated STEM programs appears to be redundant and included only to satisfy the acronym. Additionally, recent literature suggests that by singling out such low level procedures as examples of the utility of mathematics learning, students may perceive mathematics as being of lesser value than the other disciplines involved (den Braber et al., 2019; Swanson, 2019). It is questionable, then, that labelling procedures that *would be already required of students* as mathematics to fulfill the need for mathematics in a STEM program is of value to either students or mathematics teachers.

5.3.2. The role of mathematics: the epistemology of integrated STEM

Promoting either a technology/engineering[92] design- or science inquiry-based process as the core instructional method for integrated STEM programs in secondary

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[91] Although not a subject of this research, there may be tension created between mathematics teachers and teachers of other subjects who may have demonstrated to students mathematically invalid techniques. Such a tension is referred to by Bell (2016) between science and technology teachers.

[92] Note that in school STEM technology and engineering are often used interchangeably or used to describe a single entity, both because engineering as a separate discipline rarely forms part of compulsory curriculums and because of the need to satisfy the E in the STEM acronym.

schools automatically casts the entire endeavour within the ambit of either of those school subjects. Even prior to the advent of STEM education, the long research history of integrated science and mathematics learning supports the bias towards mathematics being ‘added to’ science-focused projects (Baldinger et al., 2020; Berlin & Lee, 2005; Pang & Good, 2000). This typecasting of mathematics into a supporting role of little mathematical value in integrated learning appears to be as long-lived as it is universal.

Even though STEM education resists definition, it is agreed that learning in a ‘real-world’ context is an essential characteristic of integrated STEM and connecting student learning to contexts of interest outside the classroom is thought to engage students in their learning, leading to higher achievement (Bryan & Guzey, 2020; English & Kirshner, 2015; Mohr-Schroeder et al., 2015). This approach skews the focus towards disciplines that are grounded in the physical world, that is, science and technology (Clark-Wilson & Ahmed, 2009; Rogers et al., 2011). However, it presents problems for learning progressions in mathematics. To Lederman and Niess (1998) and McComas and Burgin (2020), this is an essential epistemological distinction – whereas knowledge in science and technology is validated by reference to the external world, mathematics is largely self-referential, relying on internal logic structures for validation. This suggests that, whilst real-world contexts are critical to learning in science and technology to create meaning, the same is not necessarily true for mathematics. Consideration of the epistemic character of integrated STEM education, and that of the component disciplines, has received only minimal attention since the inception of integrated STEM education, however over recent years research interest has grown as the nature of learning progressions and knowledge building in integrated STEM comes under scrutiny (Baldinger et al., 2020; Clarke, 2014; Tytler, 2020; Tytler et al., 2019).

As discussed above, science and technology must make use of selected mathematical procedures (even if not recognised as such), and so these disciplines *rely* on the supporting role of mathematics to construct knowledge (Herschbach, 2011). On the other hand, mathematics constructs knowledge independently (Wong, 2018). This is not to say that students will not benefit from the *application* of their mathematics learning, and this is encouraged to some extent by the NSW curriculum documents. The NSW mathematics syllabus encourages certain learning areas to be applied to 'real-life' situations, 'real-life' problems and 'real-life' contexts (17 references collectively in the stages 4 and 5 syllabus) (Board of Studies NSW, 2012a). However, it does imply that the role of mathematics within the 'real-world' scope of an integrated STEM program *is* in supporting the construction of knowledge in technology or science due to the dominance of these epistemologies. Regulators interviewed in this study (Section 4.3.6) acknowledged this fundamental dilemma with mathematics in STEM education: "…maths is the tool that we use in STEM education … So, while those other subjects are able to create those contexts easily, a maths teacher's left with actually still teaching the students the tool" (REG1) and "I just think it's more time consuming for you to authentically place the maths in a STEM environment" (REG3).

The mathematics as a 'queen or servant' argument loses relevance when it is considered that it may simply not be possible, nor desirable, to anticipate *extensive* mathematics learning as taking place in such integrated STEM programs due to epistemological differences. Muller (2009) argues that disciplines such as mathematics are characterised by an internal conceptual coherence which imposes constraints on attempts to integrate, especially with disciplines with strong contextual coherence such as technology and science. In contemplating integrating across disciplines with different epistemologies and coherences, it is necessary to be aware that "not everything goes with everything" (Muller, 2009, p. 217) and to look only for opportunities where contextual coherences coincide. This is illustrated by Tytler et al. (2019)'s description of a successful thematically based integrated STEM project that accommodated most of the programmed science and technology curriculum outcomes, but only some of the mathematics outcomes, so that more of the mathematics curriculum was purposefully taught outside the project.

Thus the importance of the role of mathematics in an integrated STEM program may lie not in the *quantity* of mathematical content included, but in the *quality* and *validity* of procedures meaningfully incorporated. Integrated STEM need not be, and probably isn't, a sum of equal parts. At the heart of the STEM transaction is recognising and respecting the different ways in which knowledge is created in the component disciplines. For largely contextually based disciplines, learning in real-world contexts has an important function in creating and confirming knowledge.

Mathematics, as a conceptually based discipline, creates knowledge largely self-referentially and does not validate knowledge externally. At the same time, mathematics learning can be *enhanced* and *enriched* with the application and extension of *already acquired* conceptual knowledge to valid real-world contexts. This may be the essential role of mathematics within an integrated STEM program – to consciously and conspicuously support and enable the construction of knowledge in those disciplines that rely on mathematics, affording the opportunity to students to apply their knowledge whilst separately creating this knowledge in mathematics.

5.3.3. Curriculum challenges

As identified in Section 5.1.1, a fundamental assumption underlying the NSW STEM strategy was that educators would be able to *align* an integrated STEM program with the overall structural requirements of the NSW education system. Comments from mathematics teachers indicate that this was not straightforward (Section 4.3.5).

> We had to teach content to Year 7 that was in the Year 8 program. (R25)
>
> STEM designers often assume mathematics skills that are far beyond the level of the student they are teaching, e.g. expecting advance(d) mathematics stage 6 skills in a stage 4 class. (R60)
>
> It is difficult to find syllabus outcomes in both science and maths that can be used in the same program - not many links. (R1)

Together, these quotes from mathematics teachers (Section 4.3.5) encapsulate the challenges faced in seeking to program and teach curriculum outcomes in an integrated STEM program. In the previous chapter, analysis of curriculum cross-over opportunities in the mathematics and science curricula presented by bivariate data and statistics and algebraic manipulation of the formula $s = \frac{d}{t}$ found stage inconsistencies and lack of congruency between language, representation and purpose in the approaches of mathematics and science (Section 4.3.5). These challenges were acknowledged by regulators (Section 4.3.5).

> …we need to have a common language so that when the maths teacher's talking about, it's the same words the science teacher's talking, and also the TAS (Technology and Applied Science) teacher is talking. (REG1)
>
> I've looked to try and integrate a STEM unit around some of the STEM share equipment… but being science that's related is actually a stage five component, as I was working through stage four mathematics. (REG2)

These findings contradict the widely held belief that a common set of values and concepts provide abundant opportunities to integrate mathematics and science (for example, Berlin & Lee, 2005; Wicklein & Schell, 1995; Zhang et al., 2015). This study responds instead to the concerns of mathematics teachers and an analysis of curriculum documents to agree with researchers such as Nelson and Slavit (2007), Meyer et al. (2010) and Wong and Dillon (2020). Rather than providing opportunities for integrated learning, finding curriculum overlaps meaningful in terms of learning to two or more disciplines is difficult and the curriculum documents themselves appear to narrow possibilities.

The differences in language and convention, together with the content/standard mismatches between mathematics and science, are not acknowledged in the curriculum documents of either discipline. Far from being trivial, they create tensions in fulfilling curriculum obligations for both subjects in an integrated program, as well as for transfer and application of student knowledge between the subjects. Curriculum barriers between mathematics and disciplines using mathematical techniques are not unique to Australia, however remain a relatively unresearched field, despite being a source of great frustration, and at times animosity, amongst teachers (Clark-Wilson & Ahmed, 2009; Dodd & Bone, 1995; Orton & Roper, 2000; Wong, 2018). These barriers lie at the very interface of where models and frameworks meet the reality of implementation in the school environment and the curriculum obligations of teachers. Awareness of these issues amongst educators reaches back some time (Cockcroft, 1982; Dodd & Bone, 1995; Hoyles et al., 2001), however they have consistently been ignored by curriculum writers (Orton & Roper, 2000; Wong, 2018).

These misalignments and incongruencies between curriculum documents are symptomatic of an overall discipline-specific curriculum structure. The discipline-specific curriculum structure forms the backbone of the “grammar of schooling” (Venville et al., 2002, p. 77) of an education system, and is reflected in the organisation and design of assessment and reporting regimes, schools (subject-specific timetabling, staff rooms and teachers) and subject-specialist teacher training, particularly in secondary education. Discipline-specific curricula are the ‘elephant in the room’ of the integrated STEM approach. At the philosophical heart of the integrated approach to education is a curriculum without discipline boundaries, organised around problems and issues with discipline knowledge emerging as relevant (Beane, 1996; Dewey, 1986). The tension between attempts at integration and system-wide discipline-specific curriculum structures is widely acknowledged (Baker & Galanti, 2017; Kang, 2019; Mockler, 2018; Tytler, 2020; Venville et al., 2002) and such attempts remain a “persistently problematic curriculum practice at the school and classroom level” (Munro, 2017, p. 36). Proponents of an integrated approach to STEM learning encourage teachers to overcome the tensions by taking innovative and flexible approaches to curriculum planning and delivery, but tend to ignore that teachers at the same time must assess and report on student progress in the separate STEM subjects within the structure of the curriculum documents and obligations.

In the Australian context, reservations have been expressed about the ability of a subject-specific education structure to accommodate integrated approaches in general (Creese et al., 2016; Way et al., 2016) and integrated STEM in particular (Timms et al., 2018). In particular, the historic orientation of the NSW curriculum style towards subject-specific academic rigour and achievement, together with the very highly detailed mathematics curriculum, have steered pedagogical choices away from any form of integrated approaches (Hughes, 2019; Isaacs et al., 2015), a situation which does not appear likely to change (ACARA, 2020b; NSW Education Standards Authority, 2020). In these circumstances, it is difficult to pinpoint where an integrated approach to STEM education lies in the NSW curriculum landscape. Authors such as McFadden and Roehrig (2017) and Guzey et al. (2016) caution that designing integrated STEM curriculum design is complex and calls on skills that teachers do not have. It is also held that reorganising the curriculum to accommodate an integrated approach is beyond the responsibilities of individual teachers and should take place at the curriculum writing level (Swanson, 2019; Wong, 2018). The effort and expertise required to write an interdisciplinary curriculum for mathematics and science is illustrated by Bissaker (2014), who describes the process as involving weekly meetings between university experts and teachers over a prolonged period. The difficult and lengthy process is described by Anderson and Li (2020) as "not a trivial task and requires subject expertise and experience in designing school-based curriculum which focuses not just on curriculum content but on potentially new pedagogical approaches" (p. 4), a daunting task indeed for teachers to contemplate in their 'spare time' and in addition to existing teaching obligations. Tytler (2020) also notes the added layer of difficulty imposed on such curriculum work by "the constraints of traditional schooling structures" (p. 38). In any event, the question remains - why should teachers be tasked to follow a path not advanced by curriculum writers?

Moreover, doubts have been raised over the actual extent of the autonomy accorded to teachers in interpreting the curriculum. Sahlberg (2010) and others (see, for example, Connell, 2013; Jackson, 2019) argue that the introduction of corporate forms of accountability into education over the course of the 21st century, such as the quantification and standardisation of teaching standards together with the introduction of national standardised testing, has led to a narrowing of the curriculum, privileging practices useful for accountability rather than innovation and creativity. This narrowing of the curriculum and tension between flexibility and accountability in the curriculum has been a recurring theme in research (Brill et al., 2018; Jackson, 2019), threatening teacher autonomy and professionalism (Howes et al., 2013). Indeed, Mockler (2018) traces a diminution in the autonomy of teachers as curriculum workers across successive drafts of the *Shape of the Australian Curriculum* (ACARA, 2020b).

5.4. Sustaining STEM for mathematics

The NSSES and consequent NSW strategy advocate for change. Successful implementation of an integrated STEM program anticipates change in the way in which curriculum learning is delivered in the component disciplines together with pedagogical change. The former operates at the structural level of the curriculum and whole school environment whilst the latter at the level of the individual teacher. This research, drawing on ideas from theories of change (see Section 2.4.1), considers the *implicit* causal assumptions underlying the change program envisaged by the NSW STEM strategy to examine structural change. Individual teacher change was considered by changes in behaviour and attitude towards the intended instructional innovation, indicating movement along the continuum described in the 'Levels of Use' framework from the *Concerns Based Adoption Model* (CBAM) (Bennett & Anderson, 2018; Hall, 1974) (Table 4 in Section 3.1.4).

5.4.1. The NSW STEM strategy and change for mathematics

The sustainability of change initiatives in education is notoriously difficult (Adams, 2007; Hargreaves & Goodson, 2006), particularly when the envisaged change is not mandatory nor embedded in the curriculum, as is the case with both the NSSES and the NSW STEM education strategy. The singular model of integrated STEM promoted relied on a number of fundamental assumptions critical to successful implementation. The discussion in Section 5.2 above questions the validity of one or all of these assumptions. The challenges experienced by mathematics teachers in implementing this model, and the acceptance of variations described by head teachers, casts doubts on whether the model of integrated STEM education promoted represents sustainable change for mathematics within the NSW school environment.

It is necessary to consider, however, the examples of successful STEM integration programs described in research, in which the assumptions appear to be validated. These programs are generally the product of a prolonged partnership with an external, university-based entity and feature extensive and sustained professional development for teachers and ongoing mentoring and consultation from academic experts (see for example Anderson & Tully, 2020; Capraro et al., 2016; Han et al., 2016; Tytler et al., 2019; Williams et al., 2016). Such support is clearly not accessible by, or available to, all schools and nor was it envisaged as *necessary* by the NSW strategy. Indeed, confining success to these circumstances challenges the supposed 'STEM for all' equity goal of STEM education (Blackley & Howell, 2015; Timms et al., 2018). And even where circumstances have prevailed to initiate a successful form of integrated STEM, researchers are wary of predicting longevity, as departures of key staff or changes in leadership focus can lead to dilution and eventual extinction of such programs (Munro, 2017; Tytler et al., 2019; Venville et al., 2002). Kezar and Gehrke (2017) warn that it takes 5 – 7 years to develop the experience, structure and confidence to embed new practices in a school environment, and reforms often founder after external agents withdraw, or regulator attention turns to other imperatives (Johnson, 2014). It is relevant to note in this regard that the dedicated STEM-NSW website hosted by the DoE was taken down in 2019 and some, but not all, resources transferred to the STEM pages on the NESA website. The focus of the educators themselves may be diverted, and this can be due to waves of successive reforms, contributing to what Viennet and Pont (2017) describe as "reform fatigue" (p. 10). In addition to the 38 national education reforms introduced in Australia between 2008 and 2014 (Viennet & Pont, 2017), at the time of the introduction of the NSW STEM strategy in 2016, secondary teachers had just completed the introduction of the NSW version of the Australian curriculum for years 7 to 10. In the years subsequent, new curriculums for senior subjects continued to be gradually introduced. Furthermore, at the time of writing, both the NSW and Australian curriculums are under review (NESA, ACARA, 2020a; 2018a).

5.4.2. Individual teacher change

This research found that, notwithstanding experiencing the challenges presented to mathematics learning, common to integrated STEM programs worldwide, mathematics teachers in NSW remain interested in finding out how STEM education can be made to work for mathematics teaching and learning. This was expressed by their recognition of the professional benefits of teaching using connected STEM strategies together with seeking long-term, intensive professional development and classroom-ready resources (Section 4.3.3). In other words, whilst rejecting the model presented by the NSW strategy, mathematics teachers as individual teachers *do not reject* incorporating the connected learning approaches of STEM education into their classroom teaching of mathematics.

The *Concerns Based Adoption Model* (CBAM) (Hall, 1974) offers frameworks of progressive levels of factors that point to the success of the implementation of an instructional innovation. Of particular interest to this research is the 'Levels of Use' model of CBAM (Bennett & Anderson, 2018; Hall, 1974) (Section 2.4.2 and Table 4 in Section 3.1.4), suggesting indicators of key changes in individual teacher behaviour that may indicate progress or otherwise along this continuum. Using these suggested indicators, and starting from a position of 'NonUse' (where there is no interest in taking actions to effect change), by expressing an *acceptance* of perceived benefits of teaching in a STEM environment, both for themselves and for students (Section 4.3.1 and Section 4.3.2), and a *curiosity* to learn more and use it in their classrooms (Section 4.3.3), mathematics teachers might be considered as having progressed to the 'Preparation' or 'Mechanical' level. These levels are characterised by seeking out information about a proposed innovation and planning and using it in the classroom. However slight, they represent what Williams et al. (2016) describes as the "disturbance in the field" (p. 31) of previous entrenched practices. This finding is consistent with a more extensive study reporting a positive change momentum experienced by teachers who participated in year-long professional development to support the development of STEM programs in their individual school environments (Anderson & Tully, 2020).

Of course, no progression is linear nor consistent, and it is relevant to consider that mathematics teachers' progress along this alternative change trajectory might be hindered by their rejection of the model proposed by the regulators. Since this model was conceived by regulators only as a lengthy collective and collaborative effort between the three STEM disciplines, no access points for individuals or small-scale efforts were envisaged or provided for by way of resources or alternative explanations. However, progress along this continuum to adopt and sustain change requires support[93]. As has been seen, support is not available from external providers of STEM programs, nor is participation in academic research programs available to all teachers and schools, and, in any event, educators legitimately turn to regulators for guidance in curriculum interpretation. The publication of the STEM Pathway programs

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provides some direction (Section 4.1.2). However, these programs apply to years 9 and 10 only, and are presented as alternatives to the delivery of the mainstream curriculum, rather than integral to such delivery. If indeed regulators are interested in sustaining the use of some form of STEM teaching and learning in the classroom, regardless of the model, it is incumbent upon them and curriculum writers to provide multiple access points, allowing teachers to adapt and adopt as appropriate to their school and classroom environment. Rather than abandoning an eventual collaborative effort for STEM education in schools, providing such multiple access points to connected STEM explanations and activities of various duration offers a realistic model and timeframe for teachers to gain, as individuals, confidence in the necessary content and pedagogical knowledge to successfully approach an integrated program.

5.5. Concluding remarks

Notwithstanding definitional disagreement, researchers acknowledge that fundamentally, STEM education should connect student learning, regardless of the degree of integration (Australian Council for Educational Research, 2016; Cetin et al., 2015; Fitzallen, 2015; Honey et al., 2014; Nathan & Pearson, 2014; Stohlmann, 2018; Timms et al., 2018; Wang, 2012). Perhaps notions of STEM education should start from this fundamental feature and empower educators to implement this feature using the opportunities and within the constraints in their local environments. Recent research such as Holmlund et al. (2018) and Bryan and Guzey (2020) have questioned whether a single, worldwide definition of STEM education is critical or indeed desirable, and in any event it is highly implausible that one would be reached. Embracing a more holistic and pragmatic view, Tytler et al. (2016) urge an acceptance of “the multiplicity of school arrangements and learning goals that are developing” (p.4). These authors’ research describes the different approaches taken, and school operational arrangements of, three successful STEM programs (Tytler et al., 2019), including one designed to take place entirely within the mathematics classroom. In each approach, the mathematics intersected *only where relevant* with other disciplines or the theme, but otherwise was ‘released’ from a formal definition of integrated STEM education to independently develop mathematical thinking. The focus was able to shift, without being constrained by the inflexibility of an integrated STEM program driven by a technology/design process or science inquiry towards a pre-determined objective (Margot & Kettler, 2019; Ríordáin et al., 2016).

The NSW STEM strategy promoted a prescriptive and singular integrated model that appears to pigeon-hole STEM education programs within technology, confining opportunities for the integration of mathematics into such programs to low level, utilitarian procedures affording little, if any, scope for the development of mathematical thinking. Although this appears to contradict the essence of integrated learning, implementation imperatives within schools demand that it needs to 'fit' somewhere in the overall single-discipline structure of the NSW and Australian curriculums. This has resulted in an uneasy landscape for STEM education for mathematics in NSW and the perception that mathematics is, in fact, incidental rather than integral to the STEM effort. This was the landscape described by all stakeholder groups in this research and succinctly, if somewhat cynically, expressed by mathematics teacher R38: "(STEM is) team teaching in a standalone course where the emphasis is placed on STE and little M is covered. This is not what it is meant to be but rather what it seems to be." (Section 4.1.2)

Despite such cynicism, mathematics teachers did recognise and embrace the opportunities afforded by ideas from STEM education and implemented within the mathematics classroom. In view of the obstacles facing any teacher in implementing a STEM program in the school environment, as well as the external assessment and reporting environment, this might appear to be a pragmatic solution. This willingness expressed by mathematics teachers to adapt, refine and reposition should be heeded by regulators by providing resources allowing multiple curriculum access points to connected STEM teaching and learning. This willingness should also be heeded by the research community in recognising STEM education not only as an emerging field, but also as an emerging practice in schools and respecting the implementation constraints of both the school and wider educational structure in negotiating a flexible pathway to encourage meaningful learning in all subject areas involved. In this latter regard, respect should also be given to the curriculum learning progressions and cognitive capabilities of students, and be motivated first and foremost by activating productive learning in the disciplines rather than insisting on generating real-world contexts where the focus on production of artefacts may eclipse learning. It is necessary to separate the ideal of an integrated curriculum structure from the goals of a STEM education strategy and focus on what is practical and possible. Rather than attempting to define STEM education, this research takes the approach of Bryan and Guzey (2020) in advocating for regulatory and research clarity in articulating what is *meant by* STEM education, what it *can* look like in the local education context and how it *aligns with* the structural components of the overall education system.

Chapter 6. Conclusion

The purpose of this research was to go beyond the rhetoric of STEM education to understand how the vision of integrated STEM introduced by the NSW STEM strategy was understood and enacted for mathematics in NSW secondary schools in the “messy complexity” (Hunter & Hoong, 2017, p. I-77) of the classroom. To do so, this research captured the overall *perceptions and experiences* of stakeholders in implementing the STEM education agenda for mathematics in secondary schools in NSW, together with *analysing the mathematics learning* taking place in implemented STEM programs as detailed in exemplar documents in the regulatory environment. Stakeholders selected in this research represent a spectrum of vantage points – the regulatory environment, tertiary educators of pre-service mathematics teachers, external STEM advisors and providers of STEM programs for secondary schools, as well as mathematics teachers themselves. Together, these vantage points form a spectrum of equal probity, offering a unique insight into the landscape of STEM education for mathematics in NSW secondary schools. In exploring this spectrum, this study departs from previous research by its focus on the *overall* implementation response, rather than on the implementation of specific, research-driven programs or models in secondary schools. In doing so, it acknowledges the dissonance between the use and understanding of STEM education in the public arena and in education research. Additionally, by analysing the mathematics learning in secondary STEM programs in the NSW context and curriculum documents, this study is uniquely positioned *to respond to research concerns* about the ambivalent role of mathematics in STEM education programs and inconsistencies in stage learning, language and conventions in the STEM curriculum documents in NSW.

Mathematics teachers were intentionally accorded the ‘loudest voice’ in this research. As a former secondary school mathematics teacher, I was interested in the encounter between mathematics teaching and integrated STEM, and I wanted to hear how mathematics teachers had experienced this encounter in their classrooms and schools. Once again, this research sought to capture the breadth of this encounter, rather than focusing on responses to specific models or programs, and to listen for indications of change in the mathematics classrooms. In doing so, the NSW model is regarded as paradigmatic for the delivery of curriculum learning in secondary school by means of an integrated STEM program or unit of work implemented within a discipline-specific education structure.

Deliberately privileging the teachers' voice also allowed for this voice to be heard in questioning the implementation assumptions of the integrated STEM strategy. Rarely are the voices of teachers and schools heard in the policy process, notwithstanding implementation success depending on their understanding, ability and willingness to effect change in the classroom (Clement, 2014; Goodson, 2001; McDonnell, 2005; OECD, 2015). This study found the landscape of integrated STEM for mathematics in NSW shared many features revealed in previous research, indicating a confused understanding and messy complexity of implementation efforts. Mathematics content in integrated STEM was limited in quantity and scope and curriculum documents difficult to align and reconcile. Although expressing frustration and disillusionment with the role of mathematics in integrated STEM models, mathematics teachers nevertheless recognised that the connected learning approaches of STEM education offered professional and student learning benefits. Rejecting the role assigned to mathematics in integrated STEM, they sought guidance and support from regulators to reframe connected learning to foreground mathematics learning in the mathematics classroom. The contribution I have made to the already vast field of STEM education research is considered next, followed by suggestions for future directions in practice, policy and research and, finally, limitations to this research.

6.1. Contribution of this research

Findings from this study were interrogated to gain insights into the understanding of and experience of mathematics in integrated STEM programs in secondary schools that might indicate sustainable change for mathematics education. In terms of the understanding and experience of integrated STEM programs, the findings validate, in the local context, previous research. They show that integrated STEM education is not well understood in the secondary school environment and implemented programs appear to focus on technology or science, with little heed to mathematics. Mathematics teachers struggled with programming mathematics content into integrated STEM units, were unable to find resources that were legitimately linked to curriculum standards, and sought guidance and professional learning to develop connected STEM learning experiences and pedagogies. These findings are consistent with those of mathematics teachers worldwide in response to STEM programs based on the fully integrated model implemented within discipline-specific education structures (Baldinger et al., 2020; Kang, 2019; Maass et al., 2019; Meyer et al., 2010; Venville et al., 2002; Weinberg & Sample McMeeking, 2017). Given the ubiquity of these findings over place and time, this study rejects a 'teacher deficit' explanation of implementation challenge. Instead, these findings are reflected back onto the NSW STEM strategy to understand whether the deficit lay in the integrated *model* promoted rather than the school environment. This was achieved by using approaches from theories of change to consider implicit causal assumptions underlying the NSW strategy.

Theories of change allow inferences to be drawn about the likely efficacy, and hence sustainability, of a strategy or policy by investigating assumptions[94] on which implementation success is predicated (Connolly & Seymour, 2015). Although not made explicit, as it the case with most strategies, underlying the NSW STEM strategy were assumptions of teacher understanding of integrated or interdisciplinary STEM education, together with teacher readiness, in terms of knowledge, pedagogy and resources, to implement it in school environments. Secondary schools were assumed to be organisationally ready for implementation and, fundamentally, it was assumed that there was sufficient alignment between the separate curriculum documents of the STEM disciplines to create integrated programs delivering meaningful curriculum learning in all participating disciplines. The divergence between these assumptions and the findings was stark. This research does not to call into question the NSW strategy specifically. This strategy promotes the model of integrated STEM commonly championed in research, and the findings are consistent with research into implementation of integrated STEM worldwide in discipline-specific education

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[94] The author acknowledges that the assumptions identified in this research are not exhaustive.

structures. Using these findings to interrogate the integrated model provides insights into why these implementation difficulties appear to prevail across these education jurisdictions generally, rather than calling into question deficiencies in individual groups of educators and schools. Applying this approach from theories of change in this study thus exposes the vulnerability of the integrated STEM model to the reality of implementation in secondary schools within a discipline-specific education structure, both generally and specifically in relation to mathematics teaching and learning,

In common with their counterparts from previous research, mathematics teachers, and indeed all stakeholders in this study, expressed disillusionment with the mathematics content included in integrated STEM units, in terms of quantity, areas of mathematics commonly included, and opportunities for conceptual mathematical development. Privileging process-driven, utilitarian applications of mathematics appears to be an almost universal feature of integrated STEM programs worldwide (ACARA, 2016; Martín-Páez et al., 2019; Stohlmann, 2018; Turşucu et al., 2017), leading to observations that mathematics is trivialised and incidental to such programs (Baker & Galanti, 2017; Clark-Wilson & Ahmed, 2009; Osborne, 2014). This inferior role of mathematics is of great concern to mathematics educators, and should be of equal concern to advocates of integrated STEM education more generally, and policy makers in particular, if there is to be progress towards attainment of STEM education goals. In recent years the distribution of discipline learning in integrated STEM has emerged as an issue of concern (for example, English, 2016a, 2016b; Maass et al., 2019). This study contributes to this discourse by considering the transactional nature, epistemology and curriculum challenges of integrated STEM to mathematics. Framing integrated STEM as a transaction negotiated between component disciplines in the school environment, the low skill-level mathematical processes typically included in integrated STEM programs deliver modest value to students' learning progress in mathematics. Conversely, since these processes are generally already embedded in the practices, if not curriculums, of the other STEM disciplines, the value of including mathematics as a specifically nominated discipline in such integrated STEM programs appears to be redundant and included only to satisfy the acronym. This common use of utilitarian applications of mathematics may be due to the epistemological nature of integrated STEM itself. Dominated by technology/engineering and science, disciplines where knowledge creation is anchored in the physical world, integrated STEM insists on a ‘real-world’ context that by definition relegates the self-referential epistemology of mathematics to a supporting role. In other words, does the very nature of integrated STEM *as it is conceived* preclude the robust participation of mathematics? As observed by a regulator in this study (Section 4.4.5): “while those other subjects are able to create those (real world) contexts easily, a maths teacher’s left with actually still teaching the students the tool” (REG3).

Further challenges are presented by the overall discipline-specific nature of education systems. This research disagrees with the claim that meaningful overlaps between curriculum documents are abundant, particularly in secondary school (Berlin & Lee, 2005; Boohan, 2016; Turşucu et al., 2017; Zhang et al., 2015). Instead, this research recognises that mathematics teachers struggle to reconcile what appear to be ‘obvious’ overlaps within the sequencing and learning progressions demanded by their curriculum documents. This position is supported by a small number of researchers such as Nelson and Slavit (2007), Meyer et al. (2010) and Wong and Dillon (2020). That successful research-reported examples of integrated STEM programs often result from prolonged periods of intensive external support only highlights the challenge presented by reconciling discipline-specific curriculum documents. This tension between curriculum documents is further manifested by content/standard misalignments and differences in language, notation and convention when describing common concepts, presenting particular issues for mathematics used in other subjects. Although raised by mathematics educators and researchers for some time, these tensions appear to be consistently ignored by curriculum writers. Together, these tensions represent a fundamental fracture-line at the interface of where models of integrated STEM meet the reality of implementation in the school environment and the curriculum obligations of teachers. There is no educational system that could be found that has introduced and sustained an entirely integrated disciplinary structure. Discipline-specific curricula remain the ‘elephant in the room’ of the integrated STEM approach – either conveniently ignored or lightly dismissed by policy and research alike. Rather than waiting for the unlikely restructuring of education systems, it is imperative for research to abandon a ‘one-size fits all’ approach to STEM education and investigate flexible approaches anchored in the reality of present-day education systems and driven by the overall goals of STEM education policies and strategies – to increase student achievement and ambition in the STEM subjects.

Whilst the sustainability of the change envisaged by the fully integrated model of STEM education promoted by the NSW STEM strategy is unlikely, this study found, somewhat surprisingly, that mathematics teachers expressed individual behavioural indicators of positive change. While rejecting the integrated STEM model, mathematics teachers recognised the benefits of the *connected learning approaches* of STEM education and sought to implement these for *mathematics and in the mathematics classroom*. In expressing this willingness to move away from individual entrenched practices and actively explore new practices in their classrooms, mathematics teachers signal ownership of implementing instructional change in the classroom. This should be encouraged and fostered by regulators.

This study has found that, rather than enhancing mathematics education, interpreting and implementing STEM education exclusively as a fully integrated model in a discipline-specific education structure may, by its very nature, narrow mathematics to repetitive, process-driven procedures. Such procedures do little to enhance student learning progress in mathematics nor engender an appreciation of and engagement in mathematics education overall. The implementation of any STEM education actions in schools and classrooms should be directed at progress towards the *goals* of the originating policy documents, recognising that there are many pathways to reach that goal. Characteristics of the local implementation environment would and should shape these pathways which nevertheless incorporate the essential connected learning approaches of STEM. This demands guidance and assistance from regulators in providing multiple curriculum access points to STEM education in the form of quality curriculum resources and professional learning.

Although this research questions the long-term sustainability for mathematics of a fully integrated model of STEM education in NSW secondary schools, it recognises that the positive attitudes of mathematics teachers towards *alternative* interpretations and implementations of STEM education, aimed specifically at progressing mathematics learning, may well have been a consequence, albeit unintended, of exposure to the fully integrated model. Research publications also indicate growing acceptance of alternative interpretations and implementation models of STEM education. For example, Murphy (2020) describes successful STEM teaching in the separate subject areas, with integrated learning taking place from time to time as demanded by the context. Turning to secondary mathematics education specifically, Tytler et al. (2019) refer to a STEM program taking place entirely within the mathematics classroom and Silk et al. (2010) speak to designing technology activities that foreground the teaching of targeted areas of mathematics. However, it must be kept in mind that journal publications, as would be expected, generally concern STEM programs where substantial support has been provided to teachers and schools by academic partners, support that is not widely available nor accessible to all educators and schools. On the other hand, articles in mathematics education journals, such as the *Australian Mathematics Journal*[95] and *Reflections*[96] and on dedicated mathematics education websites, such as *Maths Inside*[97], provide resources that overcome epistemological hurdles by using mathematics learning as the starting point in real world contexts. As expressed by a mathematics teacher responding to the web survey (Section4.5):

> There is an amazing array of Maths in most subjects but programs both internally developed and externally provided seem to use Maths as a minor part of the course or project rather than the rich source of tools that could be used to develop and discover STEM concepts. (R38)

6.2. Future directions in practice, policy and research

This subsection takes up the challenges posed above and suggests areas of action that may go some way towards resolving or mitigating their impact.

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[95] For example, the recent article by Easton et al. (2020) foregrounding mathematics in digital technology.

[96] The journal of the Mathematics Association of NSW, the professional body representing mathematics teachers in NSW.

[97] https://www.uts.edu.au/research-and-teaching/our-research/maths-inside or https://www.aamt.edu.au/Better-teaching/Classroom-resources/Maths-Inside

6.2.1. Access to quality STEM education resources for mathematics

As in the European context, in Australia there is a "maze of STEM resources online" (European Schoolnet, 2018, p. 21) of vastly varying quality and overwhelmingly not specifically referenced to mathematics curriculum documents. Quality resources foregrounding mathematics in STEM education exist and are constantly being supplemented, however remain spread across a variety of publications and platforms, posing problems to teacher access. A carefully curated resource bank[98] of user-friendly connected learning activities in mathematics is required to foster innovation and experimentation. Resources linked directly to the relevant outcomes in the online mathematics curriculum pages would be both accessible to all teachers and emphasise connected learning as an everyday approach to mathematics learning in the classroom rather than an optional activity. In the local context, these resources align with initiatives announced in the *NSW Mathematics Strategy, 2025* (NSW Department of Education, 2020c).

6.2.2. A connected-curriculum experience for teachers and students

It is beyond this research to overcome the strictures of a specific-discipline curriculum structure. However, taking a 'connected-curriculum' approach to student learning enables both teachers and students to see beyond the boundaries of the individual subjects whilst preserving and respecting the different means and purposes of knowledge-creation within those boundaries. The on-line format of all curriculums in NSW affords regulators the opportunity to *directly connect the curriculums* by inserting *reciprocal* links in the curriculum documents to provide mathematics *and other* teachers with insights into both their own curriculum and those of other disciplines. This should extend beyond the STEM disciplines to include all school subjects that use mathematics in classroom learning. These insights should include

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[98] The resource bank Scootle, managed by Education Services Australia and supported by the Australian Government Department of Education, provides a high-quality foundation for extension into connected learning experiences. https://www.scootle.edu.au/ec/p/home

information about where and how learning in relevant mathematics outcomes is used in other subject areas, together with any differences in language, notation and convention commonly used in that other area. Armed with this information, mathematics teachers can demonstrate to students the myriad of ways in which their mathematics learning is used and, importantly, clarify the differences students may encounter in using the same concept or technique across subjects. These cross-curriculum links might also encourage other discipline teachers to seek support from mathematics teachers for particular mathematical techniques used in their curriculum documents. A further consideration is the local publication of comprehensive guides such as the UK *“The Language of Mathematics in Science”* (Boohan, 2016) explaining not only the differences in language, but also in notation and interpretation.

The misalignment of content and standards between curriculum documents presents challenges that can only be addressed at curriculum writing level. It is understood that this is a complex issue raising concerns about, inter alia, learning sequences in individual subject areas as well as curriculum ownership. However, whilst they persist, so will the use of “voodoo maths” tricks (Wong & Dillon, 2019, p. 792) as non-mathematics teachers compensate for their students’ lack of the particular mathematical knowledge required for the lesson to progress.

6.2.3. Realigning the STEM education conversation through research

Tytler et al. (2016) urge an acceptance of “the multiplicity of school arrangements and learning goals that are developing” (p.4) in STEM education: research needs to investigate and report this multiplicity. Continuing research into the role and distribution of discipline learning in STEM education programs will provide valuable insight into the development of programs targeting mathematics as a specific focus within schools. This research has contributed to the existing discussion of the recurring phenomena of the dominance of technology/engineering or science over mathematics in integrated STEM, however more needs to be done to determine how mathematics learning progressions can be validly advanced within some form of integrated or connected environment. Baldinger et al. (2020) found that of 4072 articles researching STEM education published in 19 STEM education research related journals from 2013-2018, only 32 described approaches that highlighted mathematics.

Clearly, if integrated or connected approaches to STEM education are to gain any traction with mathematics educators, there is a need for research to explore how mathematics learning can be positioned validly at the forefront for at least part of an integrated program. In the latter respect, it is necessary to recognise that mathematics need not be tied to the overall integrated program and instead may participate as and when legitimate curriculum learning can take place. The flexibility of the approaches described by Tytler et al. (2019) and Murphy (2020) is appealing in this regard. Continuing research in the relatively recent field of the epistemology of STEM would validate the identification of coherent epistemological overlaps to guide research programs.

Baldinger et al. (2020) also make the point that, of the 32 articles describing integrated programs highlighting mathematics, only two took place in the mathematics classroom. This is an important observation considering the enthusiasm expressed by mathematics teachers in this research to use approaches from STEM education in their classrooms. This research advocates that innovative approaches to STEM education must be accessible to all teachers and students, and not predicated on a whole-school focus, resourcing or participation in lengthy research programs. Accordingly, this research supports the proposal of those authors in calling for "new research to design integrated STEM curricula that can be implemented by secondary mathematics teachers in mathematics classrooms" (Baldinger et al., 2020, p. 86), with the caveat that any such research must at the same time respond to the local curriculum obligations and be communicated via channels commonly used by mathematics teachers (as suggested in Section 6.2.1).

The process of design thinking, an approach to problem solving used extensively across creative and business enterprises, is often used *in* STEM education. It might also be used *on* STEM education itself by providing a practical framework for research through its initial focus on the end-user experience (teachers and schools) and iterative process of questioning assumptions, proposed solutions and indeed the problem itself. This process reverses the focus from taking a theory-based model into schools for investigation to *starting* the design process with the realities of the school structures and education system, together with the goals of the originating STEM policies. This approach speaks to Cain and Allan (2017)'s recommendation that researchers should attempt to ask the same questions that teachers do and supports the recommendation of Tytler (2020) that researchers should develop “in partnership with systems and teachers, structured activity sequences that represent exemplar interdisciplinary curricular practice” (p. 38).

In the previous chapter the lack of rationale behind the NSW STEM strategy was discussed (Section 5.2.1). Although the model of integrated STEM education has intuitive logical appeal, there is no conclusive evidentiary base for its choice (see Section 2.3). This is not surprising, as the unique implementation variables in local environments cannot be controlled and hence methodologies of evaluations are idiosyncratic. Abandoning the idea that there will be a one-size-fits-all solution to STEM education opens the doors to examining the many permutations that are already taking place in NSW secondary schools, as well as the opportunity to articulate the purpose, features and benefits of particular approaches. Scalability of any *particular* model may well be impossible and indeed undesirable. Perhaps, rather than seeking this ‘Holy Grail’ of STEM education, sustainability and hence scalability should instead be focused on the dissemination of approaches and resources that keep the STEM education conversation alive, vibrant, accessible and above all relevant to both teachers and students.

6.3. Limitations of current study

Limitations on this research are evident in the design. The intent was to gain a topographical view of the STEM landscape for mathematics in NSW secondary schools pursuant to the NSW STEM strategy. The choice of four stakeholder groups necessarily neglected the views of other stakeholders in both school and STEM education, such as parents and industry. Gaining insight into a wide range of mathematics teachers’ perceptions and experience of STEM education involved a trade-off in depth over breadth, meaning that a deeper exploration of thoughtful observations was not possible. Additionally, at the time of writing, both the NSW curriculum and the Australian curriculum are under review. Whilst there appears to be a renewed emphasis on providing opportunities for students to integrate knowledge and the practical applications of knowledge, there is no indication that the overall single-discipline structure will be abandoned (ACARA, 2020b; NSW Education

Standards Authority, 2020). Finally, the vast amount of existing and current research into STEM education is in itself a limitation, and it is not possible to be confident that all relevant literature has been considered in this study.

Any research is necessarily a snapshot in time and limited by data available at that particular time. The story of STEM education is evolving, as are the actions of the various stakeholders involved in this study. The continuing efforts of teachers and schools to adopt STEM education approaches have been referred to above. This research also acknowledges that regulators have continued to be active advocates for STEM education, focusing on mathematics in a broader sense than that originally appearing in the NSW STEM strategy.

Returning to the local context, the location of STEM education in the NSW education landscape as either an innovative form of curriculum delivery or simply learning in the three component school subjects has never been clear. The vision broadcast by the Australian *National STEM School Education Strategy 2016-2026* (NSSES) (Education Council, 2015) blended the two understandings of STEM education, but neglected to provide any detail of the rationale and mechanics of achieving its goals within the existing education structure. This unenviable task was left to the individual education jurisdictions, and it is not surprising that the NSW school STEM strategy in turn lacked clarity of purpose and vision. Regulators are inevitably caught between their political masters of the day and their more enduring constituents, in the case of education, the teaching and school environment. Increasingly, the politics of education policy has become a crowded arena where attempts to reconcile many ‘interested parties’ are negotiated. It must also be noted that the timeframe leading up to the release of the NSW STEM strategy was tight. The NSSES was announced in December 2015 and the NSW STEM strategy, or parts thereof that related to integrated school STEM education, appeared in June 2016. Although NSW regulators had been working on an implementation agenda prior to the introduction of the

NSSES[99], it is nevertheless a short timeframe to introduce a reform to achieve the ambitious agenda announced therein - improving the STEM achievement of Australian school children to vouchsafe the economic future of the nation. As the OECD (2015) observes, "…the political world has its own logic and time frames that are not necessarily in line with time frames required for sustained and consolidated (education) reform" (p. 157).

6.4. Concluding remarks

This research concludes that 'stand-alone' integrated curriculum STEM programs, as promoted by the NSW STEM strategy, are not sustainable in that form for the teaching and learning of mathematics in NSW secondary schools. The groundswell of interest surrounding the arrival of the STEM education in NSW secondary schools has consolidated around an understanding of the acronym as simply referring to education in the component disciplines, eclipsing references to large scale attempts at curriculum integration. It is now routine for schools to use STEM simply as collective shorthand for science, technology and mathematics, as in 'STEM faculties' and 'STEM students'. Political and regulatory interest appears to have also waned. The dedicated *STEM-NSW* website, launched by the NSW Department of Education in 2016, was retired in 2019, with selected content transferred to other regulatory websites[100]. Notably the *NSW Mathematics Strategy 2025* (NSW Department of Education, 2020c) makes no mention of integrated, interdisciplinary or cross-curricular learning. Nevertheless, it is arguable that the routine use of the acronym in schools, as mentioned above, indicates a heightened awareness of connections between the subjects, even if they are not acted on in the manner originally envisaged. This awareness by mathematics teachers was evidenced in this research. Although the ship of integrated curriculum STEM education has arguably sailed (to paraphrase Colley

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[99] The STEM Project programs were produced as a result of schools' participation in the 2015 Stage 4 Integrated STEM project (4.3).

[100] See https://education.nsw.gov.au/teaching-and-learning/curriculum/key-learning-areas/stem and https://educationstandards.nsw.edu.au/wps/portal/nesa/k-10/understanding-the-curriculum/programming/stem-support

(2020, p. 26)), the unforeseen legacy of the integrated STEM endeavour observed in this research is not the *rejection* by mathematics teachers of integrated STEM for mathematics. Rather, the legacy lies in the ownership expressed by mathematics teachers in charting a *different* path by rethinking and reconfiguring ideas activated by STEM education to improve the learning experience of their students.

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List of Appendices

Appendix A

Common Interview Questions

1. In your opinion, what are the essential characteristics of STEM education or education in a STEM environment?
2. What do you think STEM education for mathematics should look like in a NSW high school classroom?
3. What are the challenges, if any, of including maths curriculum content in STEM programs and services for high schools?
4. Do you think all maths content can be taught in a STEM environment, or only part? If part, which content areas do you think are suited to the STEM environment?
5. What do you think are the benefits of teaching maths in a STEM environment:
   a. For students
   b. For teachers
6. What do you think are the challenges of teaching maths in a STEM environment:
   a. For students
   b. For teachers
7. Do you think the Australian Curriculum for Mathematics, in its NSW form, supports teaching maths in a STEM environment:
   a. Content
   b. Structure
8. What do you believe the long-term impact of STEM education on maths teaching and learning will be?

Appendix B

Web survey questionnaire

Welcome and thank you. My name is Jane Martin and I am a maths teacher and PhD student at UTS. My research is looking at STEM (Science, Technology, Engineering and Mathematics) and mathematics education in NSW secondary schools.The purpose of this online survey is to find out about high school maths teachers' understanding and perceptions of STEM education and the impact, if any, STEM education is having on maths teaching in the classroom. You DO NOT need to have had any experience or exposure to STEM education to respond to the survey questions - I am interested in your understanding and perceptions.

In this online survey I will ask you to answer questions and at times ask for comments, if you wish to give them. You can change your mind at any time and stop completing the survey without consequences. The survey should take about 10-15 minutes to complete.

This survey DOES NOT IDENTIFY YOU in any way and IP addresses ARE NOT collected from responses. If you have concerns about the research that you think either I or my supervisor can help you with, please feel free to contact me at jane.l.martin@student.uts.edu.au or my supervisor, Associate Professor Anne Prescott, at Anne.Prescott@uts.edu.au.

If you would like to talk to someone who is not connected with the research, you can contact the UTS Research Ethics Officer on 02 9514 9772 or Research.ethics@uts.edu.au and quote this reference ETH18-2204. Ethics approval has also been obtained from the NSW Department of Education SERAP 2018282.

Section 1: Just a few details about you as a maths teacher.

These details will not be used to identify your response in any way.

* 1. I currently teach:

☐ Year 7 maths
☐ Year 8 maths
☐ Year 9 maths (any course)
☐ Year 10 maths (any course)
☐ Year 11 maths (any course)
☐ Year 12 maths (any course)
☐ Other (please specify)

* 2. My school is located in:

○ Metropolitan Sydney
○ Regional NSW
○ Rural NSW
○ I don't teach in NSW

* 3. My school is in the:

○ Public sector
○ Catholic sector
○ Independent sector

* 4. I have been teaching maths for:

○ less than a year
○ 1 - 5 years
○ 5 - 10 years
○ 10 years +

* 5. I am a:

○ classroom teacher teaching maths only
○ classroom teacher teaching maths and another subject
○ classroom teacher teaching maths with a leadership role such as Year Advisor
○ Other (please specify)
○ Head of Department / Head Teacher (Maths)
○ Head of Department / Head Teacher (Other)

Appendix B

Section 2: What does STEM education mean?

In this section I am interested in what the term STEM education means to you as a secondary school maths teacher in NSW. It doesn't matter if you have not had any personal experience with, or exposure to, STEM education in your professional practice.

* 6. As a maths teacher, what do you think STEM education looks like specifically in secondary mathematics education? Please choose the options which BEST fit your understanding.

☐ Optional activities or clubs for students, such as coding or robotics.

☐ Team teaching in separate, time limited project(s) which cover some of the outcomes in the maths, science or technology syllabuses.

☐ Another thing teachers are meant to do.

☐ Using examples from the other STEM subjects in maths class to make connections with science, technology or engineering.

☐ Team teaching in a standalone STEM course where all outcomes in the maths, science and technology syllabuses are covered.

☐ I don't know as I have never heard of STEM education.

☐ Other (please specify) - I am interested in your understanding.

Section 3: STEM education program(s) in your school (past or present).

In this section I am interested in any STEM education programs that have been implemented in your current or previous school(s), regardless of your level of involvement, if any. If you have not had any exposure to STEM education programs, you will be directed to questions asking you about the benefits and challenges to both teachers and students that you believe might flow from teaching maths in a STEM environment.

* 7. Does your school have a formal STEM education program or programs, or is the school planning to put one in place?

○ Yes

○ No (your next question will be about the benefits and challenges of STEM)

○ Other (please specify)

* 8. Which year groups are involved (or will be involved) in the STEM program(s)?

☐ Year 7

☐ Year 8

☐ Other (please specify)

☐ Year 9

☐ Year 10

* 9. Student participation in the STEM program (check as many as are applicable):

☐ Optional curriculum offering e.g. a Stage 5 offering.

☐ Compulsory part of the curriculum.

☐ Other (please specify)

☐ Extra curricula activities or clubs.

* 10. Design and implementation: is the STEM program:

☐ Designed and implemented by teachers in the school (this includes programs designed by teachers after external professional development)?

☐ Sourced from NESA and implemented by the school?

☐ Other (please specify)

☐ Sourced from an external provider and implemented by the school?

☐ Designed and implemented by paid external providers?

Section 4: Your involvement in teaching maths in a STEM program.

In this section I am interested in your personal professional experience in teaching maths in a STEM program of any kind. If you have not had any experience, you will be directed to later in the survey.

* 11. Have you been involved in teaching maths in Stages 4 and/or 5 in a STEM program of any kind?

○ Yes

○ No, but I would like to be (your next question will be about the benefits and challenges of STEM).

○ No, and I am not interested (thank you, you will now be directed to the end of the survey).

* 12. What type of STEM program was it?

○ Fully integrated with one or more other subjects and teachers and lasting a full term or more.

○ Fully integrated with one or more other subjects and teachers and lasting less than a term.

○ Other (please specify)

○ A small project in maths class only.

* 13. Are (or were) maths classes timetabled separately to the integrated STEM program?

○ Yes there were separate maths classes to teach maths content.

○ No all maths content was taught as part of STEM program classes.

○ Other (please specify)

* 14. Were all necessary maths content and syllabus outcomes completed during the STEM program?

○ Yes

○ No

○ Not applicable - all necessary maths content had been previously taught.

○ Dont know yet - the program is ongoing.

○ Other (please specify)

* 15. What maths content area was taught as part of the STEM program.

☐ Number

☐ Algebra

☐ Measurement

☐ Geometry

☐ Other (please specify)

☐ Probability

☐ Statistics

☐ Working Mathematically

16. Would you like to comment about the content and level of maths taught and/or used as part of the STEM program?

* 17. How long did the project last?

○ 3 - 5 weeks or more

○ Other (please specify)

○ less than 3 weeks

* 18. Was the project programmed and designed by maths teachers only?

○ Yes

○ Other (please specify)

○ No, other subject teachers had input into the programming and design

* 19. Were the maths outcomes assessed as part of the STEM program?

○ Yes ALL maths outcomes in the STEM program were assessed as part of the program.

○ Yes SOME maths outcomes in the STEM program were assessed as part of the program.

○ None of the above - please give details of how the maths outcomes in the STEM program were assessed.

○ No maths outcomes in the STEM program were NOT assessed as part of the program.

Appendix B

* 20. How were the maths outcomes in the STEM program assessed? Please select as many as are applicable to your STEM program.

☐ As part of a student presentation and/or folio of work at the end of the program.

☐ As part of the student folios of work throughout the duration of the program.

☐ By worksheets and tests throughout the program for the maths outcomes.

☐ Other forms of assessment were carried out - please give details.

☐ By ongoing formative assessment throughout the project.

☐ By a maths test at the end of the project.

Section 5: The benefits and challenges in using STEM education to teach maths.

In this section I am interested in the benefits and challenges you experienced, or believe might flow, to your teaching and to the students from teaching maths in a STEM environment in stages 4 & 5. I have used 'STEM environment' to describe STEM programs of any type, i.e. as part of a formal STEM program or simply using ideas and examples from STEM in your maths classroom.

* 21. Do you think using ideas from STEM education can improve your teaching in Stages 4 and 5?

○ Yes ○ No

* 22. What benefits FOR STUDENTS have you observed, or think are likely, from teaching maths in a STEM program or using ideas from STEM in your classroom? Please check as many boxes as you think are relevant.

☐ Students are more engaged.

☐ Student performance in maths assessment tasks improved.

☐ Students are interested in practical applications of maths.

☐ None

☐ Other (please specify)

* 23. What benefits FOR TEACHERS have you observed, or think are likely, from teaching maths either in a formal STEM program or using ideas from STEM in your classroom? Please check as many boxes as you think are relevant.

☐ Teaching is more interesting.

☐ Classroom management is easier.

☐ I have enjoyed learning more about maths and how it connects to, or is used in, other subjects.

☐ None.

☐ Other (please specify)

* 24. What are the challenges FOR STUDENTS that you have observed, or think are likely, from learning maths either in a formal STEM program or using ideas from STEM in your classroom? Please check as many boxes as you think are relevant.

☐ Students need a lot of support and often don't know what they are meant to do.

☐ Students avoid using their maths and resort to trial and error instead.

☐ Lower achieving students struggle to use their maths without a lot of support.

☐ Other (please specify)

☐ Higher achieving students are not challenged by the maths in the STEM program.

☐ None.

* 25. What are the challenges FOR TEACHERS that you have experienced, or think are likely to flow, from teaching maths either in a formal STEM program or using ideas from STEM in your classroom? Please check as many boxes as you think are relevant.

☐ Lack of resources, e.g. technology, equipment, physical space.

☐ Timetabling for the project and/or for teachers to team teach

☐ Timetabling to give teachers enough time to plan and design the program or project.

☐ Other maths teachers aren't interested.

☐ Teachers from other STEM subjects aren't interested.

☐ It is difficult to program maths into STEM programs and projects.

☐ It is difficult to cover maths outcomes in sufficient depth in STEM programs and projects.

☐ Other (please specify)

☐ STEM programs seem to use easier applications of maths.

☐ STEM programs seem to use the same maths outcomes over and over.

☐ It is difficult to find STEM resources which are properly linked to maths syllabus outcomes.

☐ Leadership in my school is not supportive.

☐ Classroom management is more difficult.

☐ I am unsure about how to teach in a STEM environment.

☐ None.

Section 6: Professional Development for teaching maths in a STEM environment.

In this section I am interested in your opinion about the most effective professional development for maths teachers wanting to teach maths in a STEM program or classroom STEM environment.

* 26. What is your preferred duration for professional development for STEM?

○ Half to one day.

○ One to five days .

○ 3 - 5 days or half days over the course of a school term.

○ More than 5 days or half days over the course of a school year.

○ Other (please give details)

* 27. What is your preferred format for delivery of professional development for STEM?

○ Large group presentations, e.g. conference.

○ Small group EXTERNAL facilitated workshops with maths teachers and/or other STEM subject teachers..

○ Small group INTERNAL facilitated workshops with maths teachers and/or STEM subject teachers in my school.

○ Other (please give details)

* 28. What content do you think is necessary for professional development for STEM (you may check more than one box)?

☐ Making connections between maths content and other STEM subject content areas

☐ Delivering connected STEM learning in a maths classroom.

☐ Programming maths outcomes in a STEM program.

☐ Assessment of maths syllabus outcomes in a STEM program.

☐ How to collaborate with other teachers to plan, program and implement a STEM program.

☐ Pedagogical skills for delivering a STEM program involving group and/or project work.

☐ Classroom management skills during the implementation of a STEM program.

☐ Other (please specify)

Thank you for your time and thoughts.

Your participation in this research is greatly appreciated. If you have any questions, please contact me at jane.l.martin@student.uts.edu.au, or my supervisor, Associate Professor Anne Prescott, at anne.prescott@uts.edu.au.

29. Is there anything else you would like to say about STEM education for maths in Stages 4 & 5, please do so here.

Appendix C

HREC approval
ETH18-2204 and
SERAP approval
SERAP 2018282

Subject: Your ethics application has been approved as low risk - ETH18-2204
Date: Wednesday, 2 May 2018 at 11:09:48 am Australian Eastern Standard Time
From: research.ethics@uts.edu.au <research.ethics@uts.edu.au>
To: Jane Martin <Jane.Martin@uts.edu.au>, Anne Prescott <Anne.Prescott@uts.edu.au>
CC: Alexandra Skinner <Alexandra.Skinner@uts.edu.au>, Karen Hill <Karen.Hill@uts.edu.au>, Michael Prince <Michael.Prince@uts.edu.au>

Dear Applicant

Your local research office has reviewed your application titled, "The impact of STEM education on mathematics education in NSW Secondary Schools.", and agreed that the application meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). I am pleased to inform you that ethics approval has now been granted.

Your approval number is UTS HREC REF NO. ETH18-2204.
You should consider this your official letter of approval. If you require a hardcopy please contact your local research office.

Approval will be for a period of five (5) years from the date of this correspondence subject to the provision of annual ethics reports to your local research office.

Your approval number must be included in all participant material and advertisements. Any advertisements on the UTS Staff Connect without an approval number will be removed.

Please note that the ethical conduct of research is an on-going process. The National Statement on Ethical Conduct in Human Research (2007) requires us to obtain reports about the progress of the research, and in particular about any changes to the research which may have ethical implications. You will be contacted when it is time to complete your first report.

Please refer to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

To access this application, please follow the URLs below:
* if accessing within the UTS network: https://rm.uts.edu.au
* if accessing outside of UTS network: https://vpn.uts.edu.au , and click on " RM6 – Production " after logging in.

If you have any queries about this approval, or require any amendments to your approval in future, please do not hesitate to contact your local research office or Research.Ethics@uts.edu.au.

REF: 12a

Education
Public Schools

Ms Jane Martin
[redacted]

DOC18/615889
SERAP 2018282

Dear Ms Martin

I refer to your application to conduct a research project in NSW government schools entitled *The impact of STEM education on mathematics education in NSW Secondary Schools*. I am pleased to inform you that your application has been approved.

You may contact principals of the nominated schools to seek their participation. **You should include a copy of this letter with the documents you send to principals.**

This approval will remain valid until 05-May-2019.

The following researchers or research assistants have fulfilled the Working with Children screening requirements to interact with or observe children for the purposes of this research for the period indicated:

Researcher name	WWCC	WWCC expires
Jane Martin	WWC0682519E	14-Apr-2020

I draw your attention to the following requirements for all researchers in NSW government schools:

- The privacy of participants is to be protected as per the NSW Privacy and Personal Information Protection Act 1998.
- School principals have the right to withdraw the school from the study at any time. The approval of the principal for the specific method of gathering information must also be sought.
- The privacy of the school and the students is to be protected.
- The participation of teachers and students must be voluntary and must be at the school's convenience.
- Any proposal to publish the outcomes of the study should be discussed with the research approvals officer before publication proceeds.
- All conditions attached to the approval must be complied with.

When your study is completed please email your report to: serap@det.nsw.edu.au
You may also be asked to present on the findings of your research.

I wish you every success with your research.

Yours sincerely

Production Note:
Signature removed
prior to publication.

Elsa Lat
R/Director, School Policy and Information Management
19 July 2018

Appendix C

Appendix D: MANSW correspondance re approvals

Subject: RE: Maths teachers online survey and call out for interviews from Head of Maths
Date: Wednesday, September 12, 2018 at 9:04:34 AM Australian Eastern Standard Time
From: Executive Officer
To: Jane Martin

Thanks for this Jane. We will make sure it makes our next eNews (hopefully going out late next week).

Darius

From: Jane Martin <Jane.L.Martin@student.uts.edu.au>
Sent: Tuesday, 11 September 2018 12:25 PM
To: Executive Officer <execofficer@mansw.nsw.edu.au>
Subject: Re: Maths teachers online survey and call out for interviews from Head of Maths

Hi Darius
Just following up on your offer below to 'advertise' my research in the next eNews'. I am not sure when the next eNews is coming out, but I hoped you could put a reminder in about my research. I have attached a short piece about it which contains all the necessary information and is less cumbersome that what I previously supplied.
Also, could you let me know when it might come out?
Thanks and kind regards
Jane

Jane Martin
Doctoral Candidate & Casual Academic
UTS FASS School of Education

From: Executive Officer <execofficer@mansw.nsw.edu.au>
Date: Wednesday, 22 August 2018 at 2:45 pm
To: ITD <jane.l.martin@student.uts.edu.au>
Subject: RE: Maths teachers online survey and call out for interviews from Head of Maths

Sorry Jane. This had dropped off my radar. Thanks for giving me a reminder.

I have posted it in the news section of our website and just posted it on our facebook page.

I will make sure it is included in our eNews which will be going out within the next fortnight.

Is there any other way I can help you?

Darius

From: Jane Martin <Jane.L.Martin@student.uts.edu.au>
Sent: Wednesday, 22 August 2018 9:55 AM
To: MANSW <execofficer@mansw.nsw.edu.au>
Subject: FW: Maths teachers online survey and call out for interviews from Head of Maths

Dear Darius
I was just following up on my previous email and wondering if there had been any progress, or anything I need to do.
Thank you
Jane
Jane Martin
Doctoral Candidate & Casual Academic

UTS FASS School of Education

From: ITD <jane.l.martin@student.uts.edu.au>
Date: Wednesday, 1 August 2018 at 1:06 pm
To: Maria Quigley <mariatquigley@gmail.com>, Executive Officer <execofficer@mansw.nsw.edu.au>
Subject: Maths teachers online survey and call out for interviews from Head of Maths

Dear Maria and Darius

I have now received Ethics approval from the UTS HREC ETH18-2204 and NSW Department of Education SERAP 2018282. The approvals are attached.
I would like now to take up your offer of sharing the online survey and the 'call out' for interview participants from Head of Maths via the MANSW Facebook page and the members via email.

Online Survey
This has been created on SurveyMonkey and is anonymous. I have attached 2 documents 'Online survey Notification' with a brief invitation together with the survey link. I have formatted the invitation in a box, both with shading and without, in word and pdf form, as I don't know which format suits you best.

Heads of Maths interview invitation
Once again, I am attaching 2 documents 'Head Teachers Notification' (word and pdf) inviting Heads of Maths to contact me to be interviewed, formatted in the same way as the online survey.

Thank you for your assistance with this. Could you let me know when they will be 'published', and of course, if there are any problems or queries, please let me know.

Sincerely
Jane
Jane Martin
Doctoral Candidate & Casual Academic
UTS FASS School of Education

From: Maria Quigley <mariatquigley@gmail.com>
Date: Tuesday, 27 March 2018 at 5:56 am
To: ITD <jane.l.martin@student.uts.edu.au>
Cc: Executive Officer <execofficer@mansw.nsw.edu.au>, Anne Prescott <Anne.Prescott@uts.edu.au>
Subject: Re: PhD student seeking interviews with Head of Maths for research

Hi Jane,

This was discussed at the executive committee meeting. Providing you can provide us with copies of your university ethics approval and SERAP approval we are happy to share an invitation to participate with our members via email and also to those teachers who are part of our MANSW Facebook page.

Please forward the approvals to our executive officer, Darius Samojlowicz, once you have them and he will share the information with our members.

Kind regards,
Maria

Sent from my iPhone

On 22 Mar 2018, at 9:28 am, Jane Martin <Jane.L.Martin@student.uts.edu.au> wrote:

> Dear Maria

My name is Jane Martin and I am a PhD student at UTS (I think we may have met…). My supervisor is Associate Professor Anne Prescott and my research concerns the impact of STEM education on classroom teaching of mathematics in Years 7 to 10 in NSW secondary schools. I am seeking to gain the perspective of a broad range of stakeholders, and a very important group is Heads of Mathematics department. I am hoping to interview a number of Heads of Mathematics across all school sectors and in metropolitan and regional NSW. I need to provide the UTS Ethics committee, SERAP and other ethics committees with a list of people who have ‘in principle’ agreed to be interviewed. Whilst I have some contacts, and Anne Prescott has many, they are not really broad enough and not really random, so I was hoping I would be able to put a ‘call out’ on the MANSW Facebook page for Heads of Mathematics who might be interested in being interviewed, subject to Ethics approvals.

I have already been in contact with Darius Samojlowicz about this (via the Executive Officer email) as I dealt with him earlier concerning gaining approval for an online survey for classroom mathematics teachers to be posted on the MANSW Facebook page and am extremely grateful for the positive response to that (once again, I needed that approval as part of my Ethics application). Anne suggested that I contact you as well in case this request needs to be put before the Executive Committee meeting today. I am attaching proposed wording for the ‘call out’ and would welcome any feedback or suggestions on wording (I am trying to make it sound appealing whilst still retaining the wording the Ethics committee needs to see) or how I might get the message out other than the MANSW Facebook page should you not feel this is appropriate.

I am also attaching the (hopefully) final online survey questions (Anne has seen them) as I thought MANSW would like to have viewed them prior to any publication of a link. The survey is currently on the Google Forms platform, which may not be the best platform for this type of survey. I am investigating other platforms, however that won’t affect the questions nor the layout.

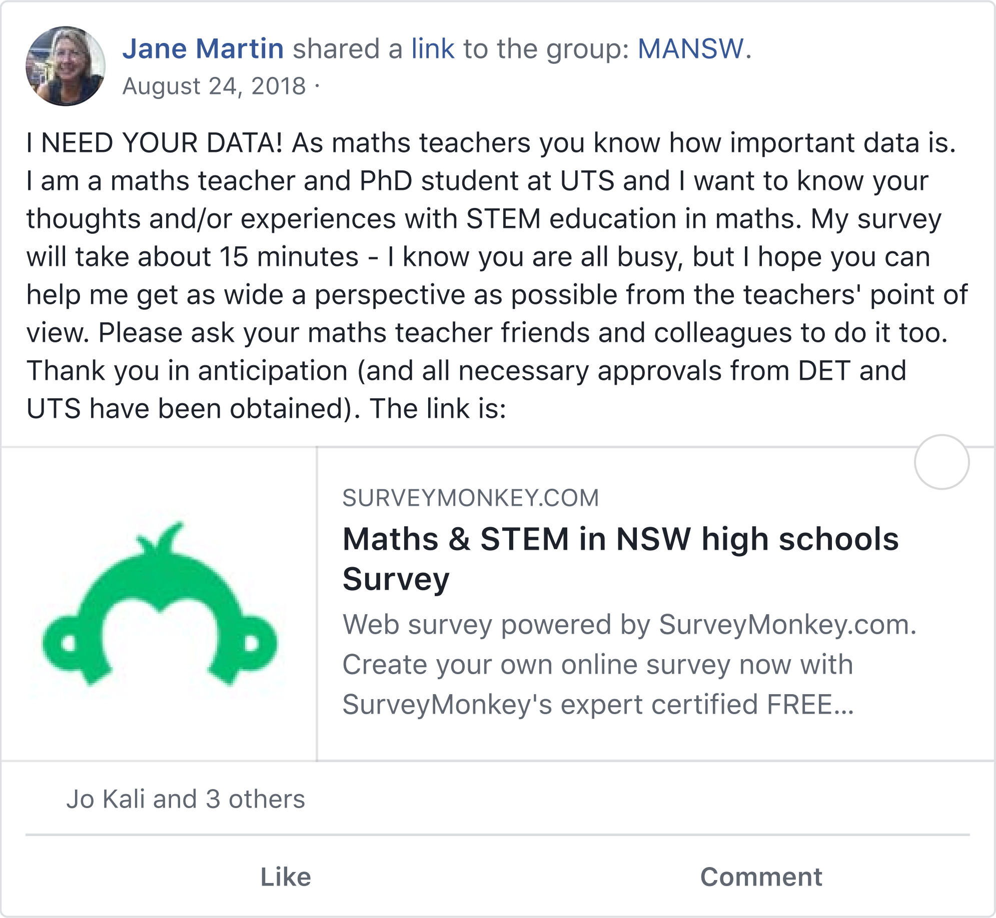
Thank you for considering this.

Regards
Jane Martin

<Heads of Mathematics research help needed.docx>

<TEACHER SURVEY v3 - Google Forms.pdf>

Appendix E: Web survey link on MANSW Facebook™ page



Jane Martin shared a link to the group: MANSW.
August 24, 2018 ·

I NEED YOUR DATA! As maths teachers you know how important data is. I am a maths teacher and PhD student at UTS and I want to know your thoughts and/or experiences with STEM education in maths. My survey will take about 15 minutes - I know you are all busy, but I hope you can help me get as wide a perspective as possible from the teachers' point of view. Please ask your maths teacher friends and colleagues to do it too. Thank you in anticipation (and all necessary approvals from DET and UTS have been obtained). The link is:

SURVEYMONKEY.COM

Maths & STEM in NSW high schools Survey

Web survey powered by SurveyMonkey.com. Create your own online survey now with SurveyMonkey's expert certified FREE...

Jo Kali and 3 others

;

Appendix F

STEM Showcase Project duration and student participation

School	Project description	Project Duration[1]			Stage 4 Year groups		Whole year group involvement	
		less than 1 term	1 term	more than 1 term	7	8	Y	N[2]
S1	Students designed a modification for a learning, social or physical school environment, in own school and in local primary school		✓			✓	✓	
S2	Design and produce a digital weather station and collect, analyse and interpret weather-related data around the school		✓			✓		✓
S3	Students designed a multi-storey structure to withstand earthquakes			✓		✓	✓	
S4	Design a transport vehicle that is not reliant on fossil fuels, within a budget			✓	✓			✓
S5	Design, construct and test a device to deliver a projectile to a target	✓			✓		✓	
S6	Design a solar-powered racing car		✓			✓		✓
S7	Design, make and evaluate a solar-powered land-based vehicle to deliver water to rural and remote communities			✓		✓		✓
S8	Design a toy for a toy company		✓		✓			✓
S9	Design and build a hydraulic-powered robotic arm		✓			✓	✓	

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[1] One school term taken as 10 – 11 weeks

[2] Classes selected on ability basis

School	Project description	Project Duration			Stage 4 Year groups		Whole year group involvement	
S10	Design and make a carbon dioxide powered car		✓		✓		✓	
		less than 1 term	1 term	more than 1 term	7	8	Y	N
S11	Design and construct: • a car powered by an electric toothbrush motor • a rescue device to escape a house • a device to measure the electrical output from a wind turbine	Information not supplied			✓			✓
S12	Create a racing vehicle	✓			✓			✓
S13	Students designed, built and tested catapults	✓				✓	✓	
S14	Students used scientific method to design, plan and construct a rocket		✓		✓		✓	
S15	Design & build: • paper plane to travel 20m • paper boat to stay afloat while holding a mass of 30 kg • a mode of transport that holds 30 kg and travels a minimum of 1 m, using a renewable energy source		✓		✓		✓	
S16	Identify an aged care or disability issue and design and build a robot to improve the quality of life of users			✓	✓		✓	
S17	Design and construct two rockets, one water powered and one air powered, aimed to outperform other rockets		✓		✓	✓	✓	

School	Project description	Project Duration			Stage 4 Year groups		Whole year group involvement	
		less than 1 term	1 term	more than 1 term	7	8	Y	N
S18	Investigate the science and mathematics of musical instruments and construct instruments to test the variables associated with sound production			✓		✓	✓	
S19	Design and construct prototypes of rockets	Project duration not specified			✓			✓
S20	Design and construct a rocket for travel to Mars, a Mars rover and a bubble to live in			✓	✓			✓
S21	Develop solutions to establish colonies in other locations in the solar system	✓				✓	✓	
S22	Design a portfolio of sport products		✓			✓	✓	
S23	Research sustainability practices for application in building designs			✓		✓		✓
S24	Design, produce, promote and evaluate a rollercoaster constructed of mainly paper			✓		✓		✓
S25	Design and create a water filtration system		✓		✓		✓	
S26	Design, make and evaluate an automated safety transport system for chemicals			✓		✓		✓
S27	Design a built environment that utilises sustainable materials and can harvest alternative sources of energy and water			✓		✓		✓

School	Project description	Project Duration			Stage 4 Year groups		Whole year group involvement	
		less than 1 term	1 term	more than 1 term	7	8	Y	N
S18	Investigate the science and mathematics of musical instruments and construct instruments to test the variables associated with sound production			✓		✓	✓	
S19	Design and construct prototypes of rockets	Project duration not specified			✓			✓
S20	Design and construct a rocket for travel to Mars, a Mars rover and a bubble to live in			✓	✓			✓
S21	Develop solutions to establish colonies in other locations in the solar system	✓				✓	✓	
S22	Design a portfolio of sport products		✓			✓	✓	
S23	Research sustainability practices for application in building designs			✓		✓		✓
S24	Design, produce, promote and evaluate a rollercoaster constructed of mainly paper			✓		✓		✓
S25	Design and create a water filtration system		✓		✓		✓	
S26	Design, make and evaluate an automated safety transport system for chemicals			✓		✓		✓
S27	Design a built environment that utilises sustainable materials and can harvest alternative sources of energy and water			✓		✓		✓

Appendix G
STEM Showcase Project subject area involvement.

School	Project description	Subject teachers involved			Class time contribution across involved subject areas			STEM delivery		
		Technology	Mathematics	Science	Technology	Mathematics	Science	Dedicated STEM lessons	Usual subject lessons	Notes
S1	Students designed a modification for a learning, social or physical school environment, in own school and in local primary school	✓	✓	✓	33.3%	33.3%	33.3%	✓	✓	additional 3 hour STEM block per fortnight.
S2	Design and produce a digital weather station and collect, analyse and interpret weather-related data around the school	✓	✓	✓	50%	15%	35%		✓	KLA teachers taught STEM independently.
S3	Students designed a multi-storey structure to withstand earthquakes	✓	✓	✓	50%	15%	35%	✓		Technology dedicated as STEM lessons; all three KLA teachers in each class
S4	Design a transport vehicle that is not reliant on fossil fuels, within a budget	✓	✓	✓	50%	25%	25%	✓	✓	additional 3 hour STEM block per week.
S5	Design, construct and test a device to deliver a projectile to a target	✓			80%	0%	20%	✓		Taught entirely by and in Technology with maths and science content integrated into Technology; extra classes from science.

School	Project description	KLA teachers involved			Class time contribution across involved KLA's			STEM delivery		
		Technology	Mathematics	Science	Technology	Mathematics	Science	Dedicated STEM lessons	Usual KLA lessons	Notes
S6	Design a solar-powered racing car	✓	✓	✓	52%	24%	24%	✓		Taught in Technology periods with extra classes from maths and science.
S7	Design, make and evaluate a solar-powered land-based vehicle to deliver water to rural and remote communities	✓			100%	0%	0%	✓		Primarily taught by Technology teachers. Other faculty teachers as required.
S8	Design a toy for a toy company	✓	✓	✓	30%	40%	30%		✓	
S9	Design and build a hydraulic-powered robotic arm	✓	✓	✓	33.3%	33.3%	33.3%	✓		Delivered in a dedicated STEM room.
S10	Design and make a carbon dioxide powered car	✓	✓	✓	62%	19%	19%		✓	Subject classes timetabled on same days for teacher and class flexibility.
S11	Design and construct: • a car powered by an electric toothbrush motor • a rescue device to escapre a house • a device to measure the electrical output from a wind turbine		✓	✓	Class contribution information not supplied					Science classes used; offer of additional classes from Maths.

School	Project description	KLA teachers involved			Class time contribution across involved KLA's			STEM delivery		
		Technology	Mathematics	Science	Technology	Mathematics	Science	Dedicated STEM lessons	Usual KLA lessons	Notes
S12	Create a racing vehicle	✓	✓	✓	One day per week. Class contribution information not supplied			✓		Classes participated if the teacher chose to take part. Technology used as dedicated STEM space.
S13	Students designed, built and tested catapults	✓	✓	✓	51%	16%	33%		✓	
S14	Students used scientific method to design, plan and construct a rocket	✓	✓	✓	50%	25%	25%		✓	
S15	Design & build: • paper plane to travel 20m • paper boat to stay afloat while holding a mass of 30 kg • a mode of transport that holds 30 kg and travels a minimum of 1 m, using a renewable energy source		✓	✓	Class contribution information not supplied			✓		One dedicated teacher assigned for all STEM lessons. It is unclear if this a Science teacher. Maths teachers also involved.
S16	Identify an aged care or disability issue and design and build a robot to improve the quality of life of users	✓		✓	50%	0%	50%		✓	
S17	Design and construct two rockets, one water powered and one air powered, aimed to outperform other rockets	✓			100%	0%	0%		✓	Technology teachers only involved.

School	Project description	KLA teachers involved			Class time contribution across involved KLA's			STEM delivery		
		Technology	Mathematics	Science	Technology	Mathematics	Science	Dedicated STEM lessons	Usual KLA lessons	Notes
S18	Investigate the science and mathematics of musical instruments and construct instruments to test the variables associated with sound production	✓	✓	✓	50%	25%	25%		✓	Term 1 delivered by Maths and Science teachers; Term 2 entirely in Technology.
S19	Design and construct prototypes of rockets	✓	✓	✓	Class contribution information not supplied			✓		

School	Project description	KLA teachers involved			Class time contribution across involved KLA's			STEM delivery		
		Technology	Mathematics	Science	Technology	Mathematics	Science	Dedicated STEM lessons	Usual KLA lessons	Notes
S20	Design and construct a rocket for travel to Mars, a Mars rover and a bubble to live in	✓	✓	✓	33%	33%	33%		✓	
S21	Develop solutions to establish colonies in other locations in the solar system	✓	✓	✓	38%	4%	58%		✓	Primarily delivered in Science.
S22	Design a portfolio of sport products	✓	✓	✓	46%	8%	46%	✓	✓	Included are two dedicated STEM classes per cycle taught by Technology.
S23	Research sustainability practices for application in building designs	✓	✓	✓	50%	25%	25%	✓		Taught in dedicated STEM learning space by Technology teacher and either a Maths or Science teacher.
S24	Design, produce, promote and evaluate a rollercoaster constructed of mainly paper	✓	✓	✓	100%	0%	0%	✓		Taught in dedicated STEM learning space by Technology teacher and either a Maths or Science teacher.

School	Project description	KLA teachers involved			Class time contribution across involved KLA's			STEM delivery		
		Technology	Mathematics	Science	Technology	Mathematics	Science	Dedicated STEM lessons	Usual KLA lessons	Notes
S25	Design and create a water filtration system	✓	✓	✓	50%	25%	25%	✓		Taught by Technology teacher within a dedicated STEM learning space with collaboration from Agriculture, Maths and Science.
S26	Design, make and evaluate an automated safety transport system for chemicals	✓			100%	0%	0%	✓		Taught by Technology teachers as a team.
S27	Design a built environment that utilises sustainable materials and can harvest alternative sources of energy and water	✓	✓	✓	100%	0%	0%	✓		Taught entirely in Technology lessons with a Maths or Science teacher joining for one lesson per cycle (6 lessons each).

Appendix H

STEM Showcase Project description and assessment

School	Project description	Portfolio	Presentation and/or product	Mathematics assessment
S1	Students designed a modification for a learning, social or physical school environment, in own school and in local primary school	✓	✓	Partial inclusion: survey data and costings
S2	Design and produce a digital weather station and collect, analyse and interpret weather-related data around the school	✓		Separate workbooks for mathematics
S3	Students designed a multi-storey structure to withstand earthquakes	✓		Partial inclusion: data, costings and graphing of costings
S4	Design a transport vehicle that is not reliant on fossil fuels, within a budget		✓	Partial inclusion: costings and graphing of costings
S5	Design, construct and test a device to deliver a projectile to a target	✓		Separate assessment for mathematics
S6	Design a solar-powered racing car	✓	✓	Partial inclusion: data collection and display
S7	Design, make and evaluate a solar-powered land-based vehicle to deliver water to rural and remote communities	✓	✓	Separate quiz. Presentation to include mathematics concepts (not specified)
S8	Design a toy for a toy company	✓	✓	No details
S9	Design and build a hydraulic-powered robotic arm	✓	✓	Common assessment rubric for folio described specific maths outcomes
S10	Design and make a carbon dioxide powered car	✓		Separate mathematics assessment

School	Project description	Portfolio	Presentation and/or product	Mathematics assessment
S11	Design and construct: • a car powered by an electric toothbrush motor • a rescue device to escape a house • a device to measure the electrical output from a wind turbine			Separate mathematics assessment and common assessment rubric for folio described specific maths outcomes
S12	Create a racing vehicle	✓		Common assessment rubric for folio described specific maths outcomes
S13	Students designed, built and tested catapults	✓		Partial inclusion: data with mean, median and mode
S14	Students used scientific method to design, plan and construct a rocket	✓		No details
S15	Design & build: • paper plane to travel 20m • paper boat to stay afloat while holding a mass of 30 kg • a mode of transport that holds 30 kg and travels a minimum of 1 m, using a renewable energy source		✓	No details
S16	Identify an aged care or disability issue and design and build a robot to improve the quality of life of users		✓	Partial inclusion: some mathematics outcomes included in folio
S17	Design and construct two rockets, one water powered and one air powered, aimed to outperform other rockets	✓		No details
S18	Investigate the science and mathematics of musical instruments and construct instruments to test the variables associated with sound production	✓		Separate mathematics assessment

School	**Project description**	**Portfolio**	**Presentation and/or product**	**Mathematics assessment**
S19	Design and construct prototypes of rockets		✓	Partial inclusion: representation of data
School	Project description	Portfolio	Presentation and/or product	Mathematics assessment
S20	Design and construct a rocket for travel to Mars, a Mars rover and a bubble to live in	✓		Separate mathematics assessment
S21	Develop solutions to establish colonies in other locations in the solar system	✓	✓	No details
S22	Design a portfolio of sport products	✓		No details
S23	Research sustainability practices for application in building designs		✓	No details
S24	Design, produce, promote and evaluate a rollercoaster constructed of mainly paper	✓		Common assessment rubric for folio described specific maths outcomes
S25	Design and create a water filtration system	✓		Partial inclusion: costings and graphing of costs in folio
S26	Design, make and evaluate an automated safety transport system for chemicals		✓	Partial inclusion: unspecified maths tasks included in portfolio
S27	Design a built environment that utilises sustainable materials and can harvest alternative sources of energy and water	✓	✓	No details

Appendix I

NESA STEM units description and assessment of mathematics syllabus outcomes

Unit name	Unit description	Assessment of mathematics syllabus outcomes		
		MA4-11NA	MA4-17MG	MA4-19SP
Game Coding	In this unit, students research and produce a computer game that will communicate to young people the effects human-built environment activities have on society and the natural environment. They create the game using a coding language and environment (e.g. visual-based programming – Scratch or Pyonkee or non-visual programming languages like Python or JavaScript). Students develop and apply skills in scientific investigation, design and the application of technological and mathematical concepts.	labelled layout design showing coordinate positions, boundaries and movement of sprites	•Questioning •Code commenting	•Class discussion/critique •spreadsheet tables and graphs

Unit name	Unit description	Assessment of mathematics syllabus outcomes				
		MA4-7NA	MA4-8NA	MA4-12MG	M4-13MG	MA4-14MG
STEM Racers	In this unit of work students produce a battery-powered or tethered power source vehicle or STEM Racer. Through a range of design, experimentation and testing procedures students are set the challenge of creating a STEM Racer with a balance of velocity, durability and aesthetic features. Throughout the design, development and practical creation of the project, student teams expand their knowledge of Science, Technology and Mathematics as they collaboratively improve and apply their content knowledge to practical problem-solving situations. To complement the hands-on practical mathematics and science applied in this unit, teams record their evidence of scientific testing, mathematical problem-solving and design successes and failures through the use of BYOD technology, culminating in the presentation of a three-minute video file highlighting their work throughout the unit.	Budget and annotated quotes included in their folio unit cost calculations	•Calculations •additional questions/quiz to test understanding and further application	•labelling in diagram (with formula and working) •additional questions/quiz to test understanding and further application	•labelling in diagram (with formula and working) •design modifications with estimated mass reductions	•investigation report included accurate calculations, with accompanying diagrams of the 3D shapes

Unit name	Unit description	Assessment of mathematics syllabus outcomes				
		MA4-7NA	MA4-12MG	M4-13MG	MA4-14MG	MA4-19SP
Water Wise	In this unit, students work through the design process in teams to address a design challenge involving water use – ‘How might we make better use of Australia’s available water?’ Students conduct first-hand investigations and secondary research related to the water cycle and water as a solvent. They develop an understanding of the need for the collection, processing and re-use of water in both rural and urban areas and the needs of an identified audience. Using this knowledge they design a system that collects and processes water for a human need.	•Use of appropriate rates and ratios language in the folio and presentation •worked calculations or explanation of the calculation process on design solution plans (e.g. sketches)	•Use of appropriate perimeter language and units in the folio and presentation •worked calculations or explanation of the calculation process on solution designs (e.g. sketches)	•Use of appropriate area language and units in the folio and presentation •worked calculations or explanation of the calculation process on solution designs (e.g. sketches)	•Use of appropriate volume language and units in the folio and presentation •worked calculations or explanation of the calculation process on solution designs (e.g. sketches)	•use of appropriate statistics and probability language •worked calculation or graphs to represent the data collected

Source: https://educationstandards.nsw.edu.au/wps/portal/nesa/k-10/resources/sample-units

Appendix J

Mathematics outcomes recorded in the 27 DoE STEM Showcase Project programs excluding Working Mathematically (WM).

Stage 4 Number and Algebra (NA)	**MA4-4NA**	**MA4-5NA**	**MA4-6NA**	**MA4-7NA**	**MA4-8NA**	**MA4-9NA**	**MA4-10NA**	**MA4-11NA**	**TOTAL**	**Percentage of total Stage 4 (WM excluded)**
Number of Project programs recording this outcome	10	10	8	17	4	0	1	4	54	42%
Percentage of individual outcome in strand appearances	19%	19%	15%	31%	7%	0%	2%	7%		
Percentage of total non-WM Stage 4 outcomes	8%	8%	6%	13%	3%	0%	1%	3%		
Stage 4 Measurement and Geometry (MG)	MA4-12MG	M4-13MG	MA4-14MG	MA4-15MG	MA4-16MG	MA4-17MG	MA4-18MG			
Number of Project programs recording this outcome	5	9	7	6	1	4	8		40	31%
Percentage of individual outcome in strand appearances	13%	23%	17%	15%	2%	10%	20%			
Percentage of total non-WM Stage 4 outcomes	4%	7%	5%	5%	1%	3%	6%			
Stage 4 Statistics and Probability (SP)	MA4-19SP	MA4-20SP	MA4-21SP							
Number of Project programs recording this outcome	21	12	1						34	27%
Percentage of individual outcome in strand appearances	62%	35%	3%							
Percentage of total non-WM Stage 4 outcomes	16%	9%	1%							

Appendix K

Mathematics outcomes recorded in the three stage 4 NESA STEM units programs excluding Working Mathematically (WM).

Stage 4 Number and Algebra (NA)	**MA4-4NA**	**MA4-5NA**	**MA4-6NA**	**MA4-7NA**	**MA4-8NA**	**MA4-9NA**	**MA4-10N**	**MA4-11N**	**TOTAL**	**Percentage of total Stage 4 (WM excluded)**
Number of Unit programs recording this outcome	1	0	1	2	0	0	0	1	5	36%
Percentage of individual outcome in strand appearances	20%	0%	20%	40%	0%	0%	0%	20%		
Percentage of total non-WM Stage 4 outcomes	7%	0%	7%	14%	0%	0%	0%	7%		
Stage 4 Measurement and Geometry (MG)	MA4-12M	M4-13MG	MA4-14M	MA4-15M	MA4-16M	MA4-17M	MA4-18M			
Number of Unit programs recording this outcome	2	2	2	0	0	1	0		7	50%
Percentage of individual outcome in strand appearances	29%	29%	29%	0%	0%	14%	0%			
Percentage of total non-WM Stage 4 outcomes	14%	14%	14%	0%	0%	7%	0%			
Stage 4 Statistics and Probability (SP)	MA4-19SP	MA4-20SP	MA4-21SP							
Number of Unit programs recording this outcome	2	0	0						2	14%
Percentage of individual outcome in strand appearances	100%	0%	0%							
Percentage of total non-WM Stage 4 outcomes	14%	0%	0%							

Appendix L

STEM Showcase Program activities attributed to mathematics syllabus outcomes for stage 4

A. Number and Algebra (NA)

Note: This is not a complete record of all activities in the Programs attributed to each syllabus outcome. Only activities that explicitly referred to and involved use of the syllabus content knowledge and skills have been recorded. Vague references using only the language of the syllabus without any elaboration in terms of the Project activity and those referring to completion using an external worksheet or web activity have been excluded, as have activities repeated across school Programs. Some activities combine outcomes both within and across strands. Activities that were incorrectly attributed have been included under the outcome nominated in the program and the correct outcome has been suggested. At times, these are stage 3 outcomes.

Although outcomes were nominated for use in the program, in some cases there was no activity attributed

Syllabus outcome and description	**MA4-4NA compares, orders and calculates with integers, applying a range of strategies to aid computation**
Activities attributed to outcome	S10: Students to investigate the use of directed numbers in developing a scale to be used to draw models of CO2 cars.
	S13: Progressively produce a functioning, safe and sturdy catapult Ask students to aim a paint-filled balloon at a grid-lined paper to produce a “splattergram” at 2 different tension settings: low and high / Students will photograph the two ‘splattergrams’ and upload them into their digital portfolios./ Students will measure the area of each splattergram and deduce the connection between area and impact force. They then have to suggest limitations to the proposed correlation between area and force (is it valid to connect these two?) and answer questions according to the task brief.
	S16: Open up Maths workbook task 1. You will need to work through this sheet as you do the challenges! Task one will cover the first 2 lessons. 2. Get the Move Straight Challenge Worksheet and your robot. 3. Work your way as a group through the challenge. Make sure you are collecting information for the Maths task as you go. 4. Answer the reflection questions which will be on the white board after the groups have finished. 5. Watch the Simple forces video. 6. Finish the Maths sheets you started for homework if required
	S17: Students make basic calculations of rocket flights
	S20: use a variety of methods to generate creative design ideas for each design project / use a design folio to record and reflect on design ideas and decisions / sketch, draw and model to aid design development / communicate information appropriate to specified audiences
	S20: No activity recorded
	S23: Students take measurements and record data Using measuring equipment to assess power usage, consumption and light / Surveying architectural features that are good/negative passive solar design / Survey and measure ventilation.
	S27: Consider the costs and financial benefits associated with renewable energy. Find out how many kilowatt hours (kWh) of electricity your home or school uses each month. Research how many solar panels you would need to produce this much energy, the costs of installing, and when you could expect to see financial benefits. Students will compare the

	cost of installing a solar powered device and if this will be of a financial benefit. Research: cost of solar power, solar production from your school, students calculate the savings and do a cost/benefit analysis of installing such a device. Our school currently has solar energy and the students can log in and check the production.
	S3: Cost of materials and budget analysis of their project using scaffold sheet
	S4: Time considerations are built in (wages).
	S5: Set up Google docs spreadsheet for collecting measurements and calculating average (Moodle Activity – 'Setting up a Google Spreadsheet to average results')
Syllabus outcome and description	**MA4-5NA operates with fractions, decimals and percentages**
Activities attributed to outcome	S10: Students will need to work in whole numbers and decimals to determine the total area.
	S16: 1. Open up Maths workbook task 1. You will need to work through this sheet as you do the challenges! Task one will cover the first 2 lessons. 2. Get the Move Straight Challenge Worksheet and your robot. 3. Work your way as a group through the challenge. Make sure you are collecting information for the Maths task as you go. 4. Answer the reflection questions which will be on the white board after the groups have finished. 5. Watch the Simple forces video. 6. Finish the Maths sheets you started for homework if required Making your robot move and turn using the programmer. Instructions: 1. Complete Maths workbook task 1 C. During lesson 2. Watch powerpoint 3. Get the Turning Challenge Worksheet and your robot. 4. Challenge Details are on Slide 8, 5. Work your way as a group through the challenge. Experiment with pivot and spin turns. Discussion Page Slide 9 6. Challenge Solution on Slide 10 7. Answer the reflection questions which will be on the projection board. 8. Watch the centripetal motion video. 9. Complete the centripetal force worksheet
	S20: No activity recorded
	S23: No activity recorded
	S25: Calculate % clarity for a water sample Light meter readings taken of clear water and dirty water – students use guided mathematics to a % of clarity i.e. Dirty reading/clear reading x100 Complete maths calculations
	S27: Consider the costs and financial benefits associated with renewable energy. Find out how many kilowatt hours (kWh) of electricity your home or school uses each month. Research how many solar panels you would need to produce this much energy, the costs of installing, and when you could expect to see financial benefits. Students will compare the cost of installing a solar powered device and if this will be of a financial benefit. Research: cost of solar power, solar production from your school, students calculate the savings and do a cost/benefit analysis of installing such a device. Our school currently has solar energy and the students can log in and check the production.
	S3: Cost of materials and budget analysis of their project using scaffold sheet
	S4: Initial design sketches and construct prototype Recap costs and review excel spreadsheets
	S6: Students interpret a range of data displays containing information about existing solar cars/electric cars, including performance proportion of use, how use has changed over time etc. This lesson will help students understand the broader purpose of their project, and how it fills a real-world need, as well as exposing them to a range of data displays and the numeracy skills necessary to interpret them

	Students use percentage composition to carry out "thought experiments" to determine the effect of varying mass of vehicle components, and generalise these results using percentages. Emphasis is on accuracy of calculations, and applications of results to all sizes Extension- multiplicative percentages, e.g. if a component that was originally 20% if the total is reduced by 40% it will now be60% time 20&% = 12% of the total Students revise circumference of a circle and carry out practical activities with Spirograph/cut out circles etc. to demonstrate the relationship between diameter and distance travelled by a wheel in a revolution, Results are calculated and recorded for different wheel diameters and different gear ratios, and made more meaningful by conversion to percentages, e.g. an increase in diameter of driver gear by 15% leads to a decrease in distance travelled of 30%. Gear ratios can also be presented as percentages to facilitate calculation of driver gear RPM given pinion gear RPM and hence the distance the wheel travels, emphasis placed on accuracy of calculations and the use of percentages to generalise conclusions Use percentages to scale from prototype to design thinking model of a vehicle that uses sustainable energy and fits a community need
	S7: Students explore a variety of representations for this data and come to conclusions about the suitability of fractions, decimals and percentages for various quantities that have been generated during the data collection process (MA4-5NA), and then make accurate statistical calculations to draw reasonable conclusions from the data (MA4-20SP)
Syllabus outcome and description	**MA4-6NA solves financial problems involving purchasing goods**
Activities attributed to outcome	S1: no activity recorded
	S23: Using data from energy audit, students to calculate the actual power consumption of each electrical device/appliance, tabulate in the table/excel with energy rating, energy in cents per kilowatt-hour, and total energy consumption and present to class.
	S26: Graphical representations of financial modelling including the calculation of GST. Budgets are reviewed. Actual vs planned finances, graphed for comparison – GST of both are calculated. Students finalising their solutions. Student finalising documentation of their designs ready for presentation. Students finalising video presentations
	S27: Consider the costs and financial benefits associated with renewable energy. Find out how many kilowatt hours (kWh) of electricity your home or school uses each month. Research how many solar panels you would need to produce this much energy, the costs of installing, and when you could expect to see financial benefits. Students will compare the cost of installing a solar powered device and if this will be of a financial benefit. Research: cost of solar power, solar production from your school, students calculate the savings and do a cost/benefit analysis of installing such a device. Our school currently has solar energy and the students can log in and check the production.
	S3: Cost of materials and budget analysis of their project using scaffold sheet Transfer information to an excel spreadsheet for analysis
	S4: Costings for each project are calculated using excel spreadsheet. Time considerations are built in (wages). present budget for each design Construct graphs of percentage of different resources and identify GST components within budget

	S8: Use their design to find what the cost of material is to build their toy. Resources is it cost effective is there any other material that will reduce costs
Syllabus outcome and description	**MA4-7NA operates with ratios and rates, and explores their graphical representation**
Activities attributed to outcome	S10: Students to investigate the use of directed numbers in developing a scale to be used to draw models of CO2 cars.
	S11: Introduce the concept of ratios, rates and speed Investigate the ratio of the diameter of the wheels front to back find the speed of each device, using the ratio distance/time by creating a start and finish line, students time how long it takes for the cars to travel the distance to the finish line
	S12: Introduce the concept of ratios, rates and speed Investigate the ratio of the circumference of wheels with width of the wheels Investigate the rotational speed of wheels, place a black dot on one wheel and find the speed of rotation, the distance travelled by the wheel in one revolution Investigate the ratio of push power and distance travelled by vehicle Investigate the speed of all vehicles by creating a start and finish line, students time how long it takes for the vehicles to travel the distance to the finish line
	S14: Analysis of results. What are or measurements telling us about speed. Calculations: Distance/time About acceleration? Can we calculate the acceleration of gravity?
	S15: Choose appropriate units of measurement for volume and convert from one unit to another (ACMMG195) − recognise that 1000 litres is equal to one kilolitre and use the abbreviation for kilolitres (kL) recognise that 1000 kilolitres is equal to one megalitre and use the abbreviation for megalitres (ML) − choose an appropriate unit to measure the volumes or capacities of different objects, e.g., swimming pools, household containers, dams use the capacities of familiar containers to assist with the estimation of larger capacities (Reasoning) − convert between metric units of volume and capacity, using 1 cm3 = 1000 mm3, 1 L = 1000 mL = 1000 cm3, 1 m3 = 1000 L = 1 kL, 1000 kL = 1 ML (this activity appears to be incorrectly attributed and should be attributed to MA4-14MG) Explicit teaching of scale drawing Scale Drawing and similar figures. Importance to have a plan drawn to scale. Successfully learn about scale drawing and drawing of similar figures.
	S16: Making your robot move and turn using the programmer. Instructions: 1. Complete Maths workbook task 1 C. During lesson 2. Watch powerpoint 3. Get the Turning Challenge Worksheet and your robot. 4. Challenge Details are on Slide 8, 5. Work your way as a group through the challenge. Experiment with pivot and spin turns. Discussion Page Slide 9 6. Challenge Solution on Slide 10 7. Answer the reflection questions which will be on the projection board. 8. Watch the centripetal motion video. 9. Complete the centripetal force worksheet
	S18: Use prior data from music survey to find the ratio amongst people who like a particular piece of music, dislike it or are neutral. Applying concept of ratios to scale factor: enlargement/reduction factor for any design. ICT application of Google Sketch-Up learnt in TAS Understand rate as a comparison of two quantities measured in different units. Identify speed as a Analyse information and calculate speed of various objects, travel, light and sound. Draw

	upon the concepts learnt in Science and calculate Speed, frequency or wavelength of sound using wave equation: wavelength.
	S19: Introduction to key ideas involved (forces, aerodynamics, balance, flight, load, projectiles, launching etc.). Variables outlined for rocket launch (volume and inclination). Hypothesis - flight time/ distance. Focus on the mathematics required during the project. This includes rearranging formulas, substituting into formulas, rates, ratios, distance, speed, time, conversion of units and other calculations required. Graphing and tabulating tools are also explored, including graphing results and presenting information visually Focus on projectile motion including graphing applications. (Full flight) Graph projectile motion Evaluate the launch including any adjustments to design and launch (e.g. angle). In teams reflect on the design and success of the launch. Record results and reflection of the launch for possible modification
	S21: Solar System sizes and distances; Light intensity and distance Model building
	S23: Using data from energy audit, students to calculate the actual power consumption of each electrical device/appliance, tabulate in the table/excel with energy rating, energy in cents per kilowatt-hour, and total energy consumption and present to class. Model making and prototyping solutions to the final design. In groups the students will make a 3D scaled model of their design. 1. Students will learn about scaling and related calculations. 2. Students will read and interpret their own plans. 3. Students will learn about the work of designers and architects. 4. Students photograph their work and blog it on Edmodo. 5. Students make 3D printed models or parts for a model. 6. Students use craft board to make architectural, design and engineering models. 7. Students can use metal and electronics to create models and solutions.
	S24: Perform simple calculations of speed, acceleration and deceleration using correct units. Practice unit conversion such as m/s to km/hr.
	S25: - Task 12 - students will look at projects already drawn on Sketch up and look at the object from top, side front and Back views to know what 2D is and what different views look like teachers guide students will create views on grid paper of simple drawings - cylinder and cone to create a bottle - grid paper drawing to go in portfolio (suggest stage 3) Students draw scaled diagram of final design including materials to be used. Scale 1:2.
	S26: sketch informal graphs to model familiar events (suggest MA7-11NA) Using the data from week 13, students graph the forces within their solution (could be in the form of force vs time)
	S27: Consider the costs and financial benefits associated with renewable energy. Find out how many kilowatt hours (kWh) of electricity your home or school uses each month. Research how many solar panels you would need to produce this much energy, the costs of installing, and when you could expect to see financial benefits. Students will compare the cost of installing a solar powered device and if this will be of a financial benefit. Research: cost of solar power, solar production from your school, students calculate the savings and do a cost/benefit analysis of installing such a device. Our school currently has solar energy and the students can log in and check the production. Students will use grid paper to create a draft scale plan of their environment.

	Student-design-groups create scaled drawings of their chosen design. Drawings are supported with notes and/or legend to clarify all details, including environmental and sustainability considerations.
	S3: Cost of materials and budget analysis of their project using scaffold sheet
	S7: Students take measurements on the solar cells and their power-generating area (MA4-13MG), and correlate these with the quantity of electricity being produced over time (MA47NA, MA4-15MG).
	S8: Uses rates and ratio in the design process Students can scale down their toy, basing their toy on a bigger item e.g. car, plane
	S9: Rates in the real world- explore reasons for 40km/h speed zones Pirrozzo Activity for rates and ratios • Group structures • ICT- SWAY task with a “big” question (SOLE), Google Forms, Google Drawings and Document sharing Big Question- Asia and Australia • Trade Ratios- countries Australia has traded with from 1950 to today Speed/Distance/Time- car race
Syllabus outcome and description	**MA4-8NA generalises number properties to operate with algebraic expressions**
Activities attributed to outcome	S17: Students watch Youtube clips of Water Rockets to gather ideas Working through project folio will cover propulsion theory, rocket parts, rocket science Students will design their own rocket using everyday objects at hand Students make basic calculations of rocket flights
	S20: Project: How Much Will my Rover Cost? Part 1: Students create a model of a Mars Rover with Lego, straws, blutac etc. (whatever is available). Each component is allocated a pronumeral and students are to develop an expression for the cost to build their Rover. Discussion: recognise that pronumerals can represent one or more numerical values (when more than one numerical value, pronumerals may then be referred to as ’variables’) Reading: How do astronauts use maths? http://mathforgrownups.com/math-at-workmonday-wendy-the-astronaut/ http://curious.astro.cornell.edu/privacy-policy/145-people-in-astronomy/careers-inastronomy/general-questions/896-how-doastronauts-use-math-in-their-jobs-beginner Worksheet: English to Algebra (modify worksheet to fit within STEM theme) Project: How Much Will my Rover Cost? Part 2: The class’s expressions are listed, and students then determine the total ‘cost’ for a combination of Rovers suitable for the Mission, describing why they chose that combination. Project: How Much Will my Rover Cost? Part 3: Students develop a range of combinations as “questions” for other students to solve. Teacher-led instruction Suitable worksheet
	S23: Using data from energy audit, students to calculate the actual power consumption of each electrical device/appliance, tabulate in the table/excel with energy rating, energy in cents per kilowatt-hour, and total energy consumption and present to class.
	S4: no activity recorded
Syllabus outcome and description	**MA4-10NA uses algebraic techniques to solve simple linear and quadratic equations**
Activities attributed to outcome	S7: Students sit a formal quiz that assess their fluency and understanding with regard to constructing, solving and interpreting equations of the forms that have arisen during prior class activities and problem-solving tasks, such as linear equations

Syllabus outcome and description	**MA4-11NA creates and displays number patterns; graphs and analyses linear relationships; and performs transformations on the Cartesian plane**
Activities attributed to outcome	S13: Collaborative develop a statement of the relationship between angle and range. E.g. as the angle (of projection) increases the range (of the projectile) increases (proportionally). Students individually prepare a table with 4 rows and 3 columns in digital portfolio with given headings to enter definitions and title Provide an image showing the path of a projectile (ball) Students individually asked to describe the path as accurately as possible using technical language Use questioning and class discussion to encourage observations regarding patterns in the vertical and horizontal "spaces" between images Direct students to measure and record vertical and horizontal "spaces" between the images Given a constant flash rate, students need to look at critical features, e.g. there is a - ● maximum height ● symmetry (vertical axis at maximum height), ● constant horizontal spacing ● vertical spacing decreases more and more as it approaches the top State the trends in both the vertical and horizontal motions. ● Observe and measure patterns in the vertical and horizontal "spaces" between images ● Tabulate results ● Write description of motion of a projectile Progressively produce a functioning, safe and sturdy catapult
	S24: Use flowcharts to examine both visually and numerically the efficiency of energy transfer in everyday situations Students are given everyday situations; discuss the forces that are operating on objects and produce diagrams to describe these forces e.g., car at traffic lights, car slowing down, car speeding up, car at constant speed. Classify each of these situations as involving balanced or unbalanced forces.
	S26: Students finalising their solutions. Student finalising documentation of their designs ready for presentation. Students finalising video presentations.
	S7: Students must research the quantitative design constraints related to their solar vehicle and develop the mathematical concepts used to understand and work within these constraints (MA4-2WM, MA4-11NA)

Appendix L

STEM Showcase Program activities attributed to mathematics syllabus outcomes for stage 4

B. Measurement and Geometry (MG)

Note: This is not a complete record of all activities in the Programs attributed to each syllabus outcome. Only activities that explicitly referred to and involved use of the syllabus content knowledge and skills have been recorded. Vague references using only the language of the syllabus without any elaboration in terms of the Project activity and those referring to completion using an external worksheet or web activity have been excluded, as have activities repeated across school Programs. Some activities combine outcomes both within and across strands. Activities that were incorrectly attributed have been included under the outcome nominated in the program and the correct outcome has been suggested. At times, these are stage 3 outcomes.
Although outcomes were nominated for use in the program, in some cases there was no activity attributed.

DoE STEM Showcase Program activities attributed to mathematics syllabus outcomes for stage 4 measurement and geometry*

Syllabus outcome and description	**MA4-12MG calculates the perimeters of plane shapes and the circumferences of circles**
Activities attributed to outcome	S16: Making your robot move and turn using the programmer. Instructions: 1. Complete Maths workbook task 1 C. During lesson 2. Watch powerpoint 3. Get the Turning Challenge Worksheet and your robot. 4. Challenge Details are on Slide 8, 5. Work your way as a group through the challenge. Experiment with pivot and spin turns. Discussion Page Slide 9 6. Challenge Solution on Slide 10 7. Answer the reflection questions which will be on the projection board. 8. Watch the centripetal motion video. 9. Complete the centripetal force worksheet
	S20: Units of Length Perimeter of other special quadrilaterals Activity: Students decide what they will need to take on a 2-1/2-year journey to Mars. Then plan how to fit everything into a 1 cubic m box, using only a measuring tape, pencil and paper. Worksheet here: http://spaceplace.nasa.gov/mathactivities/en/ Project: What will our pod look like? Part 1. Class determines parameters, and each student is to design living quarters that meet the criteria. Parameters should include minimum land area, a range of shapes, maximum perimeters etc. Project: What will our pod look like? Part 2. Students calculate the perimeter and area of their pod. Students present their pod diagram for display.
	S23: On a map of the school, students identify rooms, buildings or spaces that may be suitable for the project. They record features of the space that can be remembered. Brainstorm ideas as whole class. Use cognitive organisers such as mind maps or PMIs to consider pros and cons for each identified space (on board). Students argue case for adopting a particular space based on identified need and suitability to criteria in design task (redesign to better meet the needs of those who use it) Model making and prototyping solutions to the final design. In groups the students will make a 3D scaled model of their design.

	1. Students will learn about scaling and related calculations. 2. Students will read and interpret their own plans. 3. Students will learn about the work of designers and architects. 4. Students photograph their work and blog it on Edmodo. 5. Students make 3D printed models or parts for a model. 6. Students use craft board to make architectural, design and engineering models. 7. Students can use metal and electronics to create models and solutions.
	S26: Measuring the Circumference of the Wheel Follow the Lines and Avoid Traffic Follow the Line, avoid detours and carry a cylinder
	S3: Make model buildings and use the shake table to determine the shape and size buildings to best withstand earthquakes
	S6: Students revise circumference of a circle and carry out practical activities with Spirograph/cut out circles etc. to demonstrate the relationship between diameter and distance travelled by a wheel in a revolution, Results are calculated and recorded for different wheel diameters and different gear ratios, and made more meaningful by conversion to percentages, e.g. an increase in diameter of driver gear by 15% leads to a decrease in distance travelled of 30%. Gear ratios can also be presented as percentages to facilitate calculation of driver gear RPM given pinion gear RPM and hence the distance the wheel travels, emphasis placed on accuracy of calculations and the use of percentages to generalise conclusions
	S8: define formulas for perimeter of plane shapes and circle Use perimeter to aid the design process - size of toy, is it in proportion? - Is there material available
Syllabus outcome and description	**MA4-13MG uses formulas to calculate the areas of quadrilaterals and circles, and converts between units of area**
Activities attributed to outcome	S10: Students sketch their balsa block onto a 1cm grid sheet and determine the total area of the shape. Students to determine the area of the block needed to construct their cars. Use the concept of area of shapes to determine how much of the block will need to cut away to allow their design to be formed.
	S22: 2. Students Design a water bottle for the GWS Giants with a volume of 750mL 3. Calculating Surface area of their bottle to ensure logo designs will fit Students design a drink bottle with specific volume and different shapes. These will be prototyped on a 3D Printer after analysis done
	S23: On a map of the school, students identify rooms, buildings or spaces that may be suitable for the project. They record features of the space that can be remembered. Brainstorm ideas as whole class. Use cognitive organisers such as mind maps or PMIs to consider pros and cons for each identified space (on board). Students argue case for adopting a particular space based on identified need and suitability to criteria in design task (redesign to better meet the needs of those who use it) Model making and prototyping solutions to the final design. In groups the students will make a 3D scaled model of their design. 1. Students will learn about scaling and related calculations. 2. Students will read and interpret their own plans. 3. Students will learn about the work of designers and architects. 4. Students photograph their work and blog it on Edmodo. 5. Students make 3D printed models or parts for a model. 6. Students use craft

	board to make architectural, design and engineering models. 7. Students can use metal and electronics to create models and solutions.
	S27: Shapes and areas Students will learn or use prior knowledge to calculate the areas of two-dimensional shapes. Students will use areas to solve related problems is of fundamental importance in many everyday situations, such as carpeting a floor, painting a room, planting a garden, establishing and maintaining a lawn, installing concrete and paving, and measuring land for farming or building construction. They will be calculating areas and the most efficient area shape with available resources. Students will move from area to volume. Discussing problems like why are most water tanks cylindrical? Students will be working with various units of measurement. Lesson on converting lengths, volumes and energy units. When planning the blue print of their plan students will be required to convert between units of measurement to enable them to draw a scale diagram. Student-design-groups create scaled drawings of their chosen design. Drawings are supported with notes and/or legend to clarify all details, including environmental and sustainability considerations.
	S3: Make model buildings and use the shake table to determine the shape and size buildings to best withstand earthquakes
	S7: Students take measurements on the solar cells and their power-generating area (MA4-13MG), and correlate these with the quantity of electricity being produced over time (MA47NA, MA4-15MG).
	S8: define formulas area of plane shapes and circle Use area to aid in the design process - size of toy, is it in proportion? is there material available?
Syllabus outcome and description	**MA4-14MG uses formulas to calculate the volumes of prisms and cylinders, and converts between units of volume**
Activities attributed to outcome	S14: Using measuring instruments. Meniscus on liquid volume, making sure of an accurate "zero".
	S15: Explicit teaching of mass, weight, volume, capacity and density. Experimentation.
	S16: 1. follow teachers examples 2. using maths task 3 for the teacher’s example 3. suggest other methods for testing the success of the robot 4 Begin the production and modifying your robot (on going testing/video journal) based on plans 5. begin editing video at home to show the major steps in production ensure video contains the major steps in production and addressing the design brief, (answering if their robot is functional for its intended purpose, safe, visually appealing and comfortable). Also mention major problems and their possible solutions. Success checklist: Have you... 1. Completed maths task 3? 2. Understood how to test your robot using weight constraints and suggested other methods of testing?
	S22: 2. Students Design a water bottle for the GWS Giants with a volume of 750mL 3. Calculating Surface area of their bottle to ensure logo designs will fit
	S23: Energy scenario comparisons Teacher Presents two futures scenarios highlighting two vastly different perspectives on life in the future (Teacher led development of mind map showing two futures involving presence and absence of recycling, resources, energy).

	Students answer questions and form their own opinion about their preferred future, why and how they can help obtain it. • What is the preferred future in regard to our school energy use? • What do we need to change in our school and why do we need to bring about the change? • How do we communicate our ideas? • Do we know enough about school energy use and what we want to change to move on to the next phase? Is sustainability possible on a small scale? Model making and prototyping solutions to the final design. In groups the students will make a 3D scaled model of their design. 1. Students will learn about scaling and related calculations. 2. Students will read and interpret their own plans. 3. Students will learn about the work of designers and architects. 4. Students photograph their work and blog it on Edmodo. 5. Students make 3D printed models or parts for a model. 6. Students use craft board to make architectural, design and engineering models. 7. Students can use metal and electronics to create models and solutions.
	S7: Students then draw together their understanding of energy generation and consumption, velocity, and material costs to make predictions about the maximise size of a vehicle that could be constructed and remain economically viable over the long term
	S8: Define formulas for volume of prisms and cylinders. Use formulas to aid the design process e.g. Size of toy, is it in proportion? Is there material available?
Syllabus outcome and description	**MA4-15MG performs calculations of time that involve mixed units, and interprets time zones**
Activities attributed to outcome	S14: Continue measurement from 'comparative' based to unit based. Learn to use measuring implements accurately Describing shapes, circles, 2D shapes symmetry. Why? What effect will it have on design? Geogebra - construct shapes (fins and noses) Design, describing shapes, repeatable patterns, tessellations Geogebra. How to open. Construct, save shapes. Transfer to word or other documents. Angles created by constructed shapes (MA4-13MG)
	S20: Pre-Test: What do you know about time? 10 mins to demonstrate. Mini-Investigation: How Old Am I? Students determine their age. Discuss why their ages differ according to orbit, and determine how large each orbit is in comparison to Earth. SOLE Lesson: Why do we have daylight savings? Would it be necessary on Mars? Or ... What time zones will be necessary on Mars? Worksheet/Google Earth: Interpret and use information related to international time zones from maps. Think Pair Share: Would we need time zones on Mars? ClickView Vid and Worksheet: International Time Zones. Debate: Time is an outdated concept. On Mars, being a slave to the clock would not be necessary
	S23: Teacher Presents two futures scenarios highlighting two vastly different perspectives on life in the future. (Teacher led development of mind map showing two futures involving presence and absence of recycling, resources, energy). Students answer questions and form their own opinion about their preferred future, why and how they can help obtain it.

	• What is the preferred future in regard to our school energy use? • What do we need to change in our school and why do we need to bring about the change? • How do we communicate our ideas? • Do we know enough about school energy use and what we want to change to move on to the next phase? Is sustainability possible on a small scale? Using data from energy audit, students to calculate the actual power consumption of each electrical device/appliance, tabulate in the table/excel with energy rating, energy in cents per kilowatt-hour, and total energy consumption and present to class.
	S24: Perform simple calculations of speed, acceleration and deceleration using correct units. Practice unit conversion such as m/s to km/hr. 3. The effect of object shape and mass on its speed. Students practice unit conversions using collected data. Students perform calculations of time and speed that involve mixed units.
	S26: calculates and describes the duration of presentation solve a variety of problems involving duration, including where times are expressed in 12-hour and 24-hour notation, that require the use of mixed units (years, months, days, hours and/or minutes) Calculate the number of frames in a video segment based on video frame rate. Create a time line for video (planning / storyboard). Calculate number of frames for still image insertion.
	S7: Students take measurements on the solar cells and their power-generating area (MA4-13MG), and correlate these with the quantity of electricity being produced over time (MA47NA, MA4-15MG).
Syllabus outcome and description	**MA4-16MG applies Pythagoras' theorem to calculate side lengths in right-angled triangles, and solves related problems**
Activities attributed to outcome	S17: no activity recorded
	S8: Demonstrate with string how Pythagoras theory works Cut out triangles to reinforce that they fit the formula Define and apply formula
Syllabus outcome and description	**MA4-17MG classifies, describes and uses the properties of triangles and quadrilaterals, and determines congruent triangles to find unknown side lengths and angles**
Activities attributed to outcome	S11: Big idea: students learn the properties of shapes and the need to have accurate angles, and symmetry - Use common conventions to mark equal intervals on their sketches - Label and name the shape of their design - Know the properties of their design - Ensure their design has symmetry as this will affect its performance
	S23: Using measuring equipment to assess power usage, consumption and light. Surveying architectural features that are good/negative passive solar design. Survey and measure ventilation. Model making and prototyping solutions to the final design. In groups the students will make a 3D scaled model of their design. 1. Students will learn about scaling and related calculations. 2. Students will read and interpret their own plans. 3. Students will learn about the work of designers and architects. 4. Students photograph their work and blog it on Edmodo. 5. Students make 3D printed models or parts for a model. 6. Students use craft

	board to make architectural, design and engineering models. 7. Students can use metal and electronics to create models and solutions.
	S8: Define properties of quadrilaterals and triangles Use these properties to ensure that the design of the toy is accurate. Use the properties to make sure that the end product fits the design
	S9: Investigate the properties of special quadrilaterals, distinguish between convex and non-convex Identify line and rotational symmetry Investigate and determine lines of symmetry and the order of rotational symmetry of polygons, including special quadrilaterals • Barrier activity • ICT- Infographic, jigsaw, Venn diagrams, Google Sites • Group work • Building and design- Pythagoras
Syllabus outcome and description	**MA4-18MG identifies and uses angle relationships, including those related to transversals on sets of parallel lines**
Activities attributed to outcome	S11: Big idea: apply angle properties to design and determine the properties of their device allowing improved design after testing - Naming convention and measuring angles - Students practice measuring angles using a protractor. Students use GeoGebra to investigate angle relationships. Students investigate other successful devices online
	S12: Big idea: apply angle properties to design and determine the angle of chassis to maximise speed and generate more power. Naming convention and measuring angles Students practise measuring angles using a protractor by following these steps: 1. Place the protractor over the angle to be measured. 2. Move the protractor so the centre of the baseline is on top of the vertex of the angle. 3. Make sure the baseline is on top of one arm of the angle. 4. Hold the protractor carefully so it does not move. 5. Count forwards from 0° along the scale until you reach the other arm of the angle. 6. The number where this arm crosses the scale tells you the size of the angle in degrees. Students use GeoGebra to investigate angle relationships.
	S13: How the firing angle can be changed Describe how the angle of launch and spring tension affects the range of a marble launched from spring launcher Students will need to describe angle, force produce a sturdy base with right angles Progressively produce a functioning, safe and sturdy catapult Adjust catapult to launch a projectile at a bullseye to assess both accuracy and reliability
	S14: Introduce but don't define the possibility of angle of trajectory as a factor in rocket launch Learn to estimate, and measure angles. Geometry bisectors, of lines and angles etc. Launch angles. Measurement. Imagining (approximating) and constructing angles. Language of angles
	S23: Model making and prototyping solutions to the final design. In groups the students will make a 3D scaled model of their design.

	1. Students will learn about scaling and related calculations. 2. Students will read and interpret their own plans. 3. Students will learn about the work of designers and architects. 4. Students photograph their work and blog it on Edmodo. 5. Students make 3D printed models or parts for a model. 6. Students use craft board to make architectural, design and engineering models. 7. Students can use metal and electronics to create models and solutions.
	S24: Describe and label angles according to distinguishing features. Practice the measurement of angles.
	S8: Define parallel and transversals Use the properties of parallel lines and traversals to aid in the development and design of the toy
	S9: Geometry in design- bridges, art, nature • ICT- office 365 Custom search, research button, class OneNote, office Lens • Angles and Robots • Cranes and Lifting capacity

Appendix L

STEM Showcase Program activities attributed to mathematics syllabus outcomes for stage 4

C. Statistics and Probability (SP)

Note: This is not a complete record of all activities in the Programs attributed to each syllabus outcome. Only activities that explicitly referred to and involved use of the syllabus content knowledge and skills have been recorded. Vague references using only the language of the syllabus without any elaboration in terms of the Project activity and those referring to completion using an external worksheet or web activity have been excluded, as have activities repeated across school Programs. Some activities combine outcomes both within and across strands. Activities that were incorrectly attributed have been included under the outcome nominated in the program and the correct outcome has been suggested. At times, these are stage 3 outcomes.
Although outcomes were nominated for use in the program, in some cases there was no activity attributed.

Syllabus outcome and description	**MA4-19SP collects, represents and interprets single sets of data, using appropriate statistical displays**
Activities attributed to outcome	S1: Use and design of authentic surveys. Teacher Resource in folder and USB. Discussion around types of data that can be collected, question types and structure and how to design a survey. Data sets shown to students and discussion around their meaning and interpretation. Group Activity – Develop survey tool and distribute to students/staff. Encourage use of technology. Learning Log - Quiet personal reflection to demonstrate an understanding of survey design, including how group managed process. Literacy Exit Slip – Students to add post-it note responses to a question posted on butcher paper "What does data look like and how can it be used?" Different tables and graphs shown and discussion around why, how and when each it used. Mathematical terminology is a focus. This may be delivered as a whole year group plenary session depending on need. Group Activity – Students to think critically about data from their own survey in terms of presentation of data and how it will inform and shape their prototype design. Students to choose a mathematical technique to display data. They also need to explain their findings using mathematical reasoning. Critical and creative thinking Information and communication technology capability Small Group Activity – 2 Design Teams to work together and share their findings re: data from survey and feedback from team and justify changes to design. Exit Slip – Design Team A to report on Design Team B's prototype using 2 stars and a wish protocol.
	S11: Big idea: determine the type of data they will be collecting and how to best display this data - Practice using spreadsheets and making displays from this information on excel - Load data obtained from their trials with their devices and determine best type of graph to display the outcomes
	S13: Enter data into excel worksheet from a given scenario ● Selects cells to highlight data range to graph table producing a column graph labelling all axes construct → test →refine →adjust process Adjust catapult to launch a projectile at a bullseye to assess both accuracy and reliability

	Correlate observations/ completed sentences from data in their spreadsheets Adjust catapult to maximise the range of the projectile
	S14: Students log data in the field (online, clipboard or sheet) that shows size of bottle (600mm coke) ml of water air pressure achieved / estimated height / Student discuss any other variables Write a list of variables which we can measure and test for. Sketch data logging sheets and learn to transform to excel sheets. Graphing of results using excel etc. Analysis of results and displays. Identify trends in data and relate theory to project for improved outcomes. Nature of data. Value of repetition and repeat-ability. Outliers. Analysis of graphical results of test flights Describing and reporting on accumulated data as well as trends.
	S15: Explicit teaching on: measurement, tools of collection, practice worksheets for students to develop skills comparing data, the types of data, organisation and displaying of data, tabulating and graphing sector, bar, frequency, line graphs, analysing data mean median mode, comparing data
	S16: Making your robot move and turn using the programmer. Instructions: 1. Complete Maths workbook task 1 C. During lesson 2. Watch powerpoint 3. Get the Turning Challenge Worksheet and your robot. 4. Challenge Details are on Slide 8, 5. Work your way as a group through the challenge. Experiment with pivot and spin turns.
	S17: • use a variety of methods to generate creative design ideas for each design project • use a design folio to record and reflect on design ideas and decisions • sketch, draw and model to aid design development • communicate information appropriate to specified audiences
	S18: Conducting survey, collecting data regarding choice of music. Construct appropriate survey questions and recording sheet Conduct survey using a collection of music pieces from different cultures to create a “Music Grab” Collect data using a rating scale: e.g. 1: dislike, 2: neutral, 3: like Organisation and representation of data using tables and graphs. Organise data using tally and frequency distribution tables Represent data using column graphs, bar graph and sector graphs
	S2: Class discussion on collecting data and why companies collect data, and type of data collected from the weather station Types of data displays useful for displaying weather station data Do a class survey and record results - favourite colour Use of technology to draw different displays Different features Between dot plots and column graphs Size of angle for sector graphs and length of section in bar graphs Analyse data from the weather station to observe any significant statistical trend or pattern Choose an appropriate display
	S20: Students develop an infographic of themselves and what they bring to Mission Mars Students construct a Graphic Overview of the topic. Identify types of graphs, discussing their attributes. Look at examples of graphs in the media, particularly the role and influence of infographics Students review and reflect on each other’s infographic. Play a game where students have to find someone who has a similar quality e.g., likes the same music, born in the same month etc.

	Teacher led activity: Creating Graphs. Review types of graphs and important features. Students to work from provided data. Worksheet or text exercise. Project: How Will We Populate Mars? Part 1. Read If the World Were a Village by David Smith and Shelagh Armstrong. https://nrich.maths.org/7725&part=note Small groups are to be allocated a page, and are to display it in a suitable graph. Presented on an A3 page to be displayed in the classroom Project: How Will We Populate Mars? Part 2. Students examine each other's graphs, choose ONE and represent it in a different type of graph using Excel.
	S21: Modern Household use Human Requirements
	S22: Class discussion that covers how representative a sample is (Resource 2). Include constraints that limit the collection of data or result in unreliable data, e.g. lack of proximity to the location where data could be collected, lack of access to digital technologies, or cultural sensitivities that may influence the results. 3. Activity that investigates and questions the selection of data used to support a particular viewpoint, e.g. the selective use of data in product advertising. 4. Data from STEM class is analysed and graphed electronically
	S23: Class brainstorm how to best find out about energy use in the school and how best to assess and analyse the results – this maybe based on the Blocks/zones or types of energy use (lighting, heating, cooling, transport). Teacher facilitates discussion using Google Docs or Office 365. Students enter results into a spreadsheet, graph results and share to on-line SharePoint Drawing conclusions from the data compiled from the energy audits. Comparing the audit data with other data available.
	S24: Students learn to manipulate and analyse the factors that affect the motion of an object by completing the following experiments, data collected using conventional and digital technologies, presented in graphical form.
	S27: Hands on sustainability activity, mathematical analysis of Sustain or Drain activity. Essential Question: What is the most efficient way to ensure the supply lasts longer and everyone gets more lollies? Students model the results of the activity, what were the different outcomes of the activity? In groups have the students represent lollies (L) algebraically and write an equation or expression. What would be the benefit of working out the most sustainable method of sharing resources? Number pattern for most efficiency = $4(2+2n)$ Students to complete Multiple intelligences survey Complete survey, record the results on the worksheet and display them graphically. Give information on different types of surveys. Discuss that this is a Likert-type scale survey. When students finish, we could discuss what the survey revealed about their learning style. Was this a valid or reliable survey? Where the learning styles in the class varied? What does this say about the group surveyed? How can this be helpful when planning groups for our project? Students will display their learning style graphs as part of a gallery in the room.
	S4: Test and evaluation of current design. Students continually evaluate existing design and modify as require following testing and experimentation.
	S5: Set up Google docs spreadsheet for collecting measurements and calculating average (Moodle Activity – 'Setting up a Google Spreadsheet to average results')
	S6: Mathematics Students interpret a range of data displays containing information about existing solar cars/electric cars, including performance,

	Students graph results of experiments relating shape of vehicle to air resistance, select the most appropriate display for the data, and use correct scales for axes Students interpret a range of data displays from various sources to answer questions about renewable versus non-renewable energy Collects and presents data from project in final report, using tables graphs
	S7: In groups, students present their findings and explain the optimal solution they have identified with mathematical justification, selecting appropriate verbal, graphical or symbolic representations to make their case (MA4-1WM, MA4-19SP).
	S9: • Tennis ball challenge • TES resource-Can I recycle it? (Relate to materials for iRobot)- Sustainability and Indigenous aspects
Syllabus outcome and description	**MA4-20SP analyses single sets of data using measures of location, and range**
Activities attributed to outcome	S11: Big idea: use their knowledge of measures of location and range to analyse the data they obtain from their trails and then determine the most effective device with appropriate reasoning from the scenario of “Rescue Me” - practice collecting data, displaying that in a frequency distribution table - analyse data and draw conclusions - make recommendations from this
	S13: construct → test →refine →adjust process Progressively produce a functioning, safe and sturdy catapult Understand and apply measures of dispersion to analyse simple measurements Understand and apply reliability and accuracy to simple measurements and by using measures of dispersion Ask students to aim a paint-filled balloon at a grid-lined paper to produce a “splattergram” at 2 different tension settings: low and high. Students will photograph the two ‘splattergrams’ and upload them into their digital portfolios. Students will measure the area of each splattergram and deduce the connection between area and impact force. They then have to suggest limitations to the proposed correlation between area and force (is it valid to connect these two?) and answer questions according to the task brief.
	S15: Explicit teaching on; measurement, tools of collection, practice worksheets for students to develop skills comparing data, the types of data, organisation and displaying of data, tabulating and graphing sector, bar, frequency, line graphs, analysing data mean median mode, comparing data Successfully complete the worksheets and power points attached to this step
	S18: Use concept of MODE identify the piece/s of music liked by most of the people (Music Grab) Use concept of Range to identify : The range of number of instruments used in various pieces of the Grab; the frequency range that human ear is able to hear learnt in science Use prior data from music survey to find the ratio amongst people who like a particular piece of music, dislike it or are neutral. Applying concept of ratios to scale factor: enlargement/reduction factor for any design. ICT application of Google Sketch-Up learnt in TAS Understand rate as a comparison of two quantities measured in different units. Identify speed as a Analyse information and calculate speed of various objects, travel, light and sound. Draw

	upon the concepts learnt in Science and calculate Speed, frequency or wavelength of sound using wave equation: wavelength. Analyse distance-time graphs and describe motion of an object over a given time period (including use of widgets on HOTMATHS). Use distance-time graphs of sound waves and the speed of sound to calculate wavelength/frequency of sound waves Understand that a given piece of music has many sound waves combined together. Use ICT to understand and then sketch graphs to represent constructive interference of sound waves in music.
	S2: Analyse data from the weather station to observe any significant statistical trend or pattern Draw conclusion from the data and predict the future results based on the projection from the present data Extrapolate line graph to make predictions about data collected from weather station in 2030 Students summaries data collected from weather station the values of the mean, median, mode and range for each set of data are recorded in the booklet Finding the mean, median, mode and range for each set of data Choose an appropriate display
	S23: Class brainstorm how to best find out about energy use in the school and how best to assess and analyse the results – this maybe based on the Blocks/zones or types of energy use (lighting, heating, cooling, transport). Teacher facilitates discussion using Google Docs or Office 365. Students enter results into a spreadsheet, graph results and share to on-line SharePoint. Drawing conclusions from the data compiled from the energy audits. Comparing the audit data with other data available
	S24: Students learn to manipulate and analyse the factors that affect the motion of an object by completing the following experiments, data collected using conventional and digital technologies, presented in graphical form
	S3: Compile data collection from tower destruction /Analyse and evaluate tower effectiveness against earthquakes
	S5: Set up Google docs spreadsheet for collecting measurements and calculating average (Moodle Activity – 'Setting up a Google Spreadsheet to average results')
	S6: Analyse data from friction experiments, select appropriate display for data, and analyse to find mean and range (two lessons) Analysis of test data to find mean, median and mode and range of speed and distance tests, under various conditions, and use that data to predict a winner on the final race Collects and presents data from project in final report, using tables graphs
	S7: Students explore a variety of representations for this data and come to conclusions about the suitability of fractions, decimals and percentages for various quantities that have been generated during the data collection process (MA4-5NA), and then make accurate statistical calculations to draw reasonable conclusions from the data (MA4-20SP)
Syllabus outcome and description	**MA4-21SP represents probabilities of simple and compound events**
	S27: In groups students learn about Venn diagrams and use these to show relationships among sets. The Venn diagrams will help the students classify environments as sustainable

Activities attributed to outcome	or unsustainable. The activity is designed to have students explore the different types of environments. following the script: To draw a Venn diagram, you first draw a rectangle which is called your "universe". In the context of Venn diagrams, the universe is not "everything", but "everything you’re dealing with right now". Let’s deal with the following list of things: houses, tents, caves, picnic areas, etc.….whatever they can think of. Students complete a quick write, share this with a partner and then as a class create a mind map of things to put in the Venn Diagram.
	S9: • Predicting outcomes through experiments • Watching some experiment designs- i.e., Myth Busters • 8 Way Maths- indigenous ideas • Domino Challenge

Appendix M

Stage 4 outcomes from the NSW Syllabus for the Australian Curriculum Mathematics K-10

Working mathematically	
MA4-1WM	communicates and connects mathematical ideas using appropriate terminology, diagrams and symbols
MA4-2WM	applies appropriate mathematical techniques to solve problems
MA4-3WM	recognises and explains mathematical relationships using reasoning
Number and Algebra	
MA4-4NA	compares, orders and calculates with integers, applying a range of strategies to aid computation
MA4-5NA	compares, orders and calculates with fractions, decimals and percentages
MA4-6NA	solves financial problems involving purchasing goods
MA4-7NA	operates with ratios and rates, and explores their graphical representation
MA4-8NA	generalises number properties to operate with algebraic expressions
MA4-10NA	uses algebraic techniques to solve simple linear and quadratic equations
MA4-11NA	creates and displays number patterns; graphs and analyses linear relationships; and performs transformations on the Cartesian plane
Statistics and Probability	
MA4-19SP	collects, represents and interprets single sets of data, using appropriate statistical displays
MA4-20SP	analyses single sets of data using measures of location, and range
MA4-21SP	represents probabilities of simple and compound events
Measurement and Geometry	
MA4-12MG	calculates perimeters of plane shapes and circumference of circles
MA4-13MG	uses formulas to calculate the areas of quadrilateral and circles, and converts between units of areas
MA4-14MG	uses formulas to calculates the volumes of prisms and cylinders, and coverts between units of volume
MA4-15MG	performs calculations of time that involved mixed units, and interpret time zones
MA4-16MG	applies Pythagoras' theorem to calculate side lengths in right-angled triangles and solves related problems.
MA4-17MG	classifies, describes and uses the properties of triangles and quadrilateral, and determine congruent triangles to find unknown side lengths and angles
MA4-18MG	identifies and uses angle relationships, including those related to transversals on sets of parallel lines

Note that these outcomes description are taken from the Table of Objectives and Outcomes – Continuum of Learning from the NSW Syllabus for the Australian Curriculum Mathematics K-10. Detailed content descriptions are found following each individual outcome and can be accessed at: https://educationstandards.nsw.edu.au/wps/portal/nesa/k-10/learning-areas/mathematics/mathematics-k-10/outcomes